Technical Report EL-96-15
September 1996

US Army Corps of Engineers
Waterways Experiment Station

Environmental Impact Research Program

Coastal Habitats in Padilla Bay, Washington: A Review

by *Douglas A. Bulthuis*
Padilla Bay National Estuarine Research Reserve

Prepared for Headquarters, U.S. Army Corps of Engineers

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Coastal Habitats in Padilla Bay, Washington: A Review

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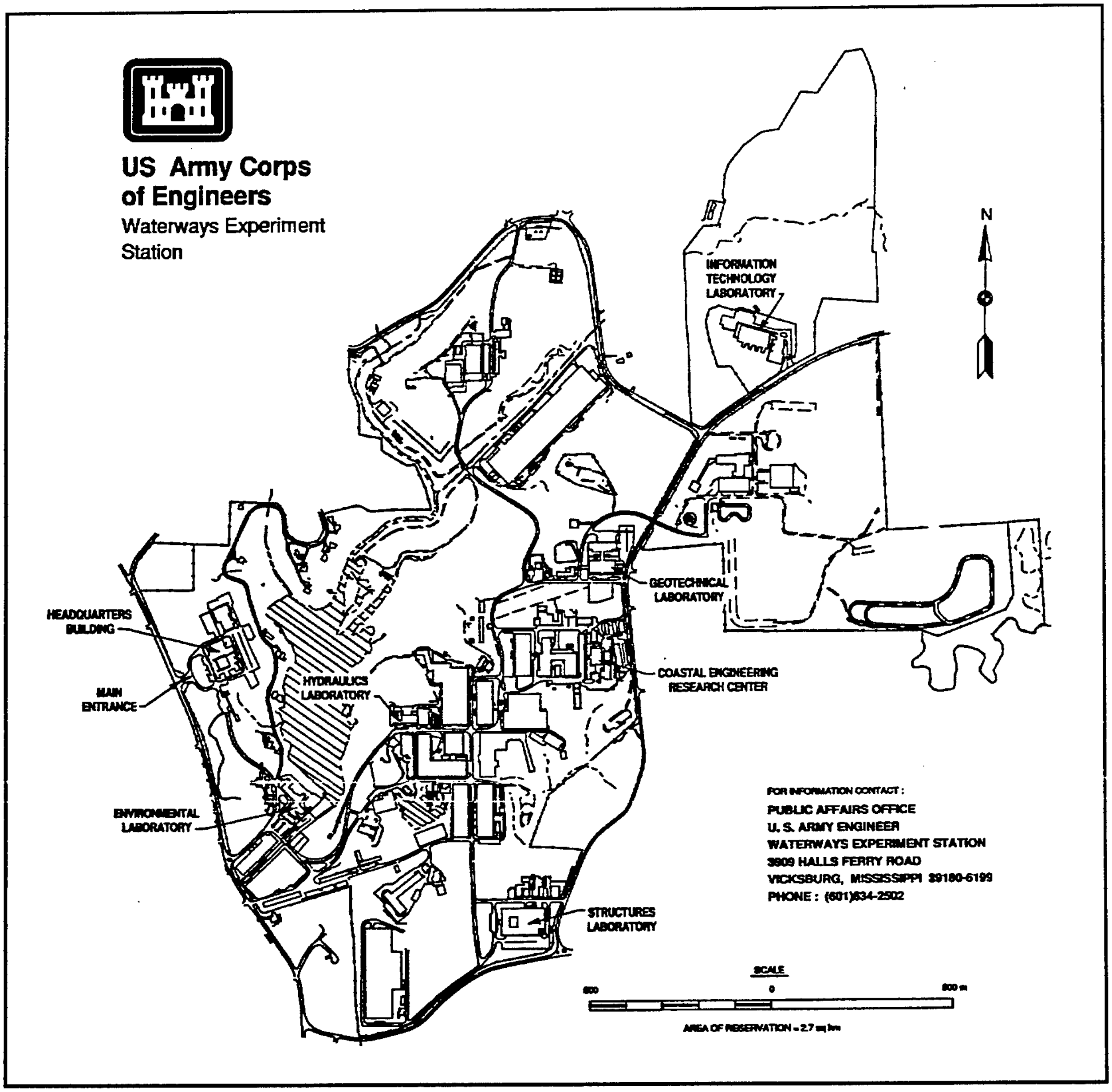
Final report

Approved for public release; distribution is unlimited

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000

Monitored by U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, MS 39180-6199



Waterways Experiment Station Cataloging-in-Publication Data

Bulthuis, Douglas A.

Coastal habitats in Padilla Bay, Washington : a review / by Douglas A. Bulthuis ; prepared for U.S. Army Corps of Engineers ; monitored by U.S. Army Engineer Waterways Experiment Station.

65 p. : ill. ; 28 cm. -- (Technical report ; EL-96-15)

Includes bibliographic references.

1. Habitat (Ecology) -- Washington -- Padilla Bay. 2. Padilla Bay (Wash.) I. United States. Army. Corps of Engineers. II. U.S. Army Engineer Waterways Experiment Station. III. Environmental Laboratory (U.S. Army Engineer Waterways Experiment Station) IV. Title. V. Environmental Impact Research Program (U.S.) VI. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; EL-96-15.

TA7 W34 no.EL-96-15

US Army Corps
of Engineers
Waterways Experiment
Station

Environmental Impact
Research Program

Coastal Habitats in Padilla Bay, Washington: A Review (TR EL-96-15)

ISSUE: The technology for successfully creating coastal habitats has outstripped the ability to assess their value or the appropriateness of individual projects. The principal difficulty with existing evaluation methods is the failure to address the issue of habitat "trade-offs," i.e., out-of-kind replacement. The purpose of this study has been to develop the framework for a new evaluation method which addresses these concerns.

RESEARCH OBJECTIVE: The Padilla Bay National Estuarine Research Reserve (PBNERR), Mount Vernon, WA, was selected as a case study site for applying a new technique for evaluating coastal habitats. The objective of this study was to summarize the structure and ecological functions of coastal habitats in Padilla Bay.

SUMMARY: The dominant communities and species assemblages of coastal habitats of the PBNERR have been described. Ecological functions of coastal habitats have been summarized.

AVAILABILITY: The report is available on Interlibrary Loan Service from the U.S. Army Engineer Waterways Experiment Station (WES) Library, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199; telephone (601) 634-2355. To purchase a copy, call the National Technical Information Service (NTIS) at (703) 487-4650. For help in identifying a title for sale, call (703) 487-4780. NTIS numbers may also be requested from the WES librarians.

About the Author: The report was written by Dr. Douglas A. Bulthuis, Research Coordinator, Padilla Bay National Estuarine Research Reserve, Mount Vernon, WA. **Point of contact** is Dr. Gary L. Ray, Marine Biologist, WES, telephone (601) 634-2589, e-mail rayg@ex1.wes.army.mil.

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Preface

This report was prepared by the Padilla Bay National Estuarine Research Reserve (PBNERR), Department of Ecology, State of Washington, for the Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), as part of the Environmental Impact Research Program (EIRP), sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE). Technical monitors were Ms. Cheryl Smith, Mr. Forrester Einarsen, and Mr. Fredrick B. Juhle, HQUSACE. Dr. Russell F. Theriot, EL, WES, was the EIRP Program Manager.

The report was written by Dr. Douglas A. Bulthuis, PBNERR, with library assistance from Ms. Sharon Riggs. The Washington State Department of Ecology and National Oceanographic and Atmospheric Administration, Office of Ocean and Coastal Research Management, cooperated in the performance of this work. Contract monitor was Dr. Gary L. Ray, Ecological Research Division (ERD), EL. Work progressed under the general supervision of Dr. Douglas G. Clarke, Acting Chief, Coastal Ecology Branch, ERD; Dr. Conrad J. Kirby, Chief, ERD; and Dr. John W. Keeley, Director, EL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

This report should be cited as follows:

> Bulthuis, D. A. (1996). "Coastal habitats in Padilla Bay, Washington: A review," Technical Report EL-96-15, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

1 Introduction

The estuarine fauna and their habitats in Padilla Bay, Washington, have been the subject of a variety of studies during the last 20 years, although there has been no review or synthesis of these studies. Concern for the habitats along the coasts of the United States has increased in recent years. To address this concern, several classification schemes have been proposed for coastal habitats (Ray 1975; Cowardin et al. 1979; Dethier 1990; Simenstad et al. 1991). Recently, Ray (1994) has proposed a Coastal Habitat Classification Scheme to provide an overall framework for evaluating coastal habitats. An early step in this process of evaluating coastal habitats is the collection and summary of existing information. The objective of this report is to collect the available data on habitats in Padilla Bay, Washington, and to review the information relevant to the habitats identified in the Coastal Habitat Classification Scheme.

Padilla Bay is located north of Puget Sound along the mainland coast of Washington at the southern end of the Strait of Georgia and directly east of the San Juan Islands. It is an "orphaned" estuary of the Skagit River (U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), and Washington State Department of Ecology 1980) with a small coastal watershed of about 9,300 ha (Bulthuis 1993b). The bay is part of the complex of estuarine straits and bays that receive fresh water from the Skagit, Nooksack, and Fraser rivers as well as numerous small coastal streams, sloughs, and rivers and is connected to the Pacific Ocean via the Strait of Juan de Fuca. Salinity in Padilla Bay ranged from about 27 to 31 parts per thousand during 1985-1986 (Cassidy and McKeen 1986) and, thus, the bay and all habitats in the bay would be categorized as "Polyhaline" in the Coastal Habitat Classification Scheme (Ray 1994).

Padilla Bay contains extensive intertidal flats that are covered by eelgrass (Bulthuis 1991). The eelgrass community is important for migratory and wintering waterfowl (Jeffrey 1976), juvenile fish (Fresh 1979; Simenstad et al. 1988), and juvenile crabs (Dinnel et al. 1986; McMillan 1991). In part because of the importance of the eelgrass meadows and associated biota, Padilla Bay was designated a National Estuarine Research Reserve in 1980 (U.S. Department of Commerce, NOAA, and Washington State Department of Ecology 1980). Because eelgrass habitat and associated biota are so important to Padilla Bay, this report begins with a review of the studies on eelgrass

habitats in Padilla Bay, followed by a review of the other intertidal habitats, and finally the subtidal habitats. The habitats in this report are delineated and defined as described by Ray (1994) and in Padilla Bay (Table 1) include:

Subtidal	Intertidal
Rock Bottom Unconsolidated Bottom: Sand Aquatic Bed: Rooted vascular	Rock Bottom: Rubble Unconsolidated Bottom: Cobble/gravel Unconsolidated Bottom: Sand Unconsolidated Bottom: Mud Aquatic Bed: Rooted vascular Aquatic Bed: Algal Marsh

Table 1
Habitats in Polyhaline System of Coastal Habitat Classification Scheme Proposed by Ray (1994)

Polyhaline
Subtidal
Rock Bottom[a]
Bedrock
Rubble
Unconsolidated Bottom
Cobble-Gravel
Sand[a]
Mud
Aquatic Bed
Rooted Vascular[a]
Algal
Reef
Worm
Mollusc
Intertidal
Rock Bottom
Bedrock
Rubble[a]
Uncosolidated Bottom
Cobble-Gravel[a]
Sand[a]
Mud[a]
Aquatic Bed
Rooted Vascular[a]
Algal[a]
Marsh[a]

[a] Those habitats that are present in Padilla Bay, Washington.

2 Coastal Habitats in Padilla Bay

Intertidal Aquatic Bed: Rooted Vascular

Intertidal eelgrass (*Zostera marina* and *Z. japonica*) is the most extensive habitat in Padilla Bay and the most important of the habitats in terms of defining the habitat value of the bay as a whole. For the last several decades, Padilla Bay has been considered a valuable estuarine embayment requiring protection primarily because of the extensive eelgrass beds and the associated fish, shellfish, and birds (Sylvester and Clogston 1958;[1] Jeffrey 1976; Jeffrey, Parker, and Henry 1977; Koons and Cardwell 1981). Preservation of the intertidal eelgrass habitat and the connected fauna was a major impetus behind the nomination and designation of Padilla Bay as a National Estuarine Research Reserve (U.S. Department of Commerce, NOAA, and Washington State Department of Ecology 1980).

Aerial extent

No estimates of aerial extent of the eelgrass beds in Padilla Bay were made until 1987 despite their recognized importance. Thom and Hallum (1990) reviewed hydrographic charts surveyed in 1987 and suggested that eelgrass may have been less widely distributed in Padilla Bay at that time, covering about 600 ha. Webber, Mumford, and Eby (1987) and Morton (1988) used satellite imagery to estimate the distribution and area of eelgrass in the bay in the mid 1980s. They distinguished four classes of seagrass cover: very sparse (less than 10-percent cover), sparse (approximately 40-percent cover), and high intertidal and low intertidal/subtidal (both with 100-percent cover). Excluding the area of very sparse coverage, Webber, Mumford, and Eby (1987) estimated 3,097 ha of eelgrass in Padilla with an additional 823 ha around March Point (Table 2). Bulthuis (1991) used color aerial photography to map the distribution and area of habitats in Padilla Bay (Table 3). Six

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1 Sylvester, R. O., and Clogston, F. L. (1958). "A study of the preoperational marine environment in the vicinity of the Texas Company Refinery Puget Sound Works, Anacortes, Washington," Unpublished report to Texas Company.

Table 2
Area of Eelgrass in Padilla Bay in 1986 as Estimated by Webber, Mumford, and Eby (1987) From Satellite Imagery

Cover Category	Area, ha
Very sparse seagrass/algae	463
Sparse seagrass cover	717
Complete seagrass cover, high intertidal	495
Complete seagrass cover, low intertidal, subtidal	1,885
Total seagrass in Padilla Bay east of Swinomish Channel	3,097

Note: Webber, Mumford, and Eby (1987) did not consider the very sparse seagrass/algae category as "seagrass" - covered habitat.

classes of seagrass cover were distinguished based on dominate species (*Zostera marina*, *Z. japonica*) percent cover (5 to 20, 21 to 50, 51 to 100 percent) and elevation (subtidal, intertidal). Total area in Padilla Bay east of Swinomish Channel (comparable with Padilla Bay as defined by Webber, Mumford, and Eby 1987) was about 3,018 ha. This estimate is surprisingly close to the estimate of Webber, Mumford, and Eby (1987) of 3,097 ha—surprising, because Webber, Mumford, and Eby (1987) indicated that the satellite imagery underestimated the subtidal areas of eelgrass and because the distribution maps differ in the area covered by eelgrass, particularly in the mid intertidal area. Webber, Mumford, and Eby (1987) estimated about 720 ha of sparse seagrass cover, which is roughly comparable with the 610 ha of *Z. marina* low-percent cover, *Z. japonica*, and intermixed *Z. marina* and *Z. japonica* of Bulthuis (1991). Therefore, these two independent studies estimated similar areal coverage of eelgrass in Padilla Bay (exclusive of March Point) of about 3,000 ha (Table 4).

Distribution within Padilla Bay

Two species of eelgrass are distributed in Padilla Bay. *Zostera marina* is a "native" eelgrass being widely distributed on the west coast of North America with a worldwide distribution that includes eastern North America and Europe. *Zostera japonica* apparently was introduced to the Pacific Northwest in the early 1900s (Harrison and Bigley 1982) and is now common on the Washington coast, northern Puget Sound, and southern Strait of Georgia. Harrison and Bigley suggest that *Z. japonica* spread to the Pacific Northwest via introduction of the Japanese oysters, *Crassostrea gigas* Thunberg. The first introduction of Japanese oysters was made in 1902 to Samish Bay, immediately north of Padilla Bay. Thus, Samish Bay and Padilla Bay may be the sites of the first introductions of *Z. japonica* to the Pacific Northwest.

Table 3
Area of Eelgrass in Padilla Bay in 1989 as Estimated by Bulthuis (1991) From Color Aerial Photography

Cover Category	Area, ha
Zostera japonica	236
Zostera japonica with *Z. marina*	81
Zostera marina 5-20 percent cover	297
Zostera marina 21-50 percent cover	839
Zosteral marina 50-100 percent cover	1,326
Subtotal intertidal *Zostera* in Padilla Bay	2,779
Zostera marina subtidal	239
Total *Zostera* in Padilla Bay east of Swinomish Channel	3,018

Note: The first five categories are intertidal.

Table 4
Area of Coastal Habitats in Padilla Bay, Washington, Based on Aerial Photography and Ground Truth Investigations in Summer 1989

Habitat	Area, ha	Percent of Padilla Bay
Intertidal		
Rock Bottom		
Rubble	<1	<1
Unconsolidated Bottom		
Cobble - Gravel	<1	<1
Sand	1,515[a]	23
Mud	350[a]	5
Aquatic Bed		
Rooted Vascular	2,960	45
Algal	220	3
Marsh	70	1
Subtidal		
Rock Bottom	<1	<1
Unconsolidated Bottom		
Sand	1,261	19
Aquatic Bed		
Rooted Vascular	252	4

Note: From Bulthuis (1991).
[a] The delineation between sand mud habitats was estimated from the total Intertidal Unconsolidated Bottom (1,865 ha).

Zostera japonica is distributed higher in the intertidal than *Z. marina* in Padilla Bay (Figure 1; Thom 1990; Bulthuis 1991). The two species grow intermixed near the upper distribution limit of *Z. marina*. Harrison (1982a,b) has shown evidence that distribution of *Z. marina* in the higher intertidal region is likely to be limited by physical factors (desiccation and temperature); when conditions are suitable for growth of *Z. marina*, it is able to grow above *Z. japonica* and outcompete *Z. japonica* for light. Thus, the lower limit of distribution of *Z. japonica* in Padilla Bay is probably determined by the upper limit of distribution of *Z. marina*.

Zostera marina is a clonal plant spreading via rhizome growth. Gene flow between clones is possible vegetatively by rhizomes or fragmentation of clones or by seed dispersal. Laushman (1993) reported allozyme variation in populations of *Z. marina* from Padilla Bay as well as False Bay, San Juan Island, Washington, and Massachusetts. He reported that the *Z. marina* population in Padilla Bay was multiclonal and did not appear to be genetically isolated. Gene flow in *Z. marina* was comparable with many terrestrial species of plants.

Interannual variation

The distribution of *Zostera marina* and *Z. japonica* in Padilla Bay varies from year to year. The broad outlines of distribution—extensive areas of the lower intertidal flats and upper subtidal covered with *Z. marina* and large areas of the mid intertidal covered with *Z. japonica*—are similar each year. However, in the mid to upper intertidal region, there appear to be large changes from one year to the next at any one location. Few studies have attempted to document the year-to-year variations in distribution of eelgrass (Orth and Moore 1986, 1987; Orth and Nowak 1990; Orth, Moore, and Nowak 1990), and only a few years of data have been collected in Padilla Bay (Bulthuis and Rogers, unpublished data). However, the information collected so far indicates that the area covered by *Z. japonica* may fluctuate widely from one year to the next (Table 5). These data indicate the importance of not relying on a single survey taken in 1 year to estimate the areas covered by eelgrass. The boundaries of coastal habitats are not fixed, but naturally fluctuate from year to year.

Eelgrass biomass and density

The density and biomass of *Zostera marina* and *Zostera japonica* have been measured by several authors at various sites in Padilla Bay. In Table 6, the density and biomass of both species of eelgrass from samples taken during summer in various studies are listed. The data cannot be compared between studies because of the different locations of the sampling sites. Several of the studies were conducted in locations where access from the shore was important in deciding placement of the sample site. Thus, populations close to

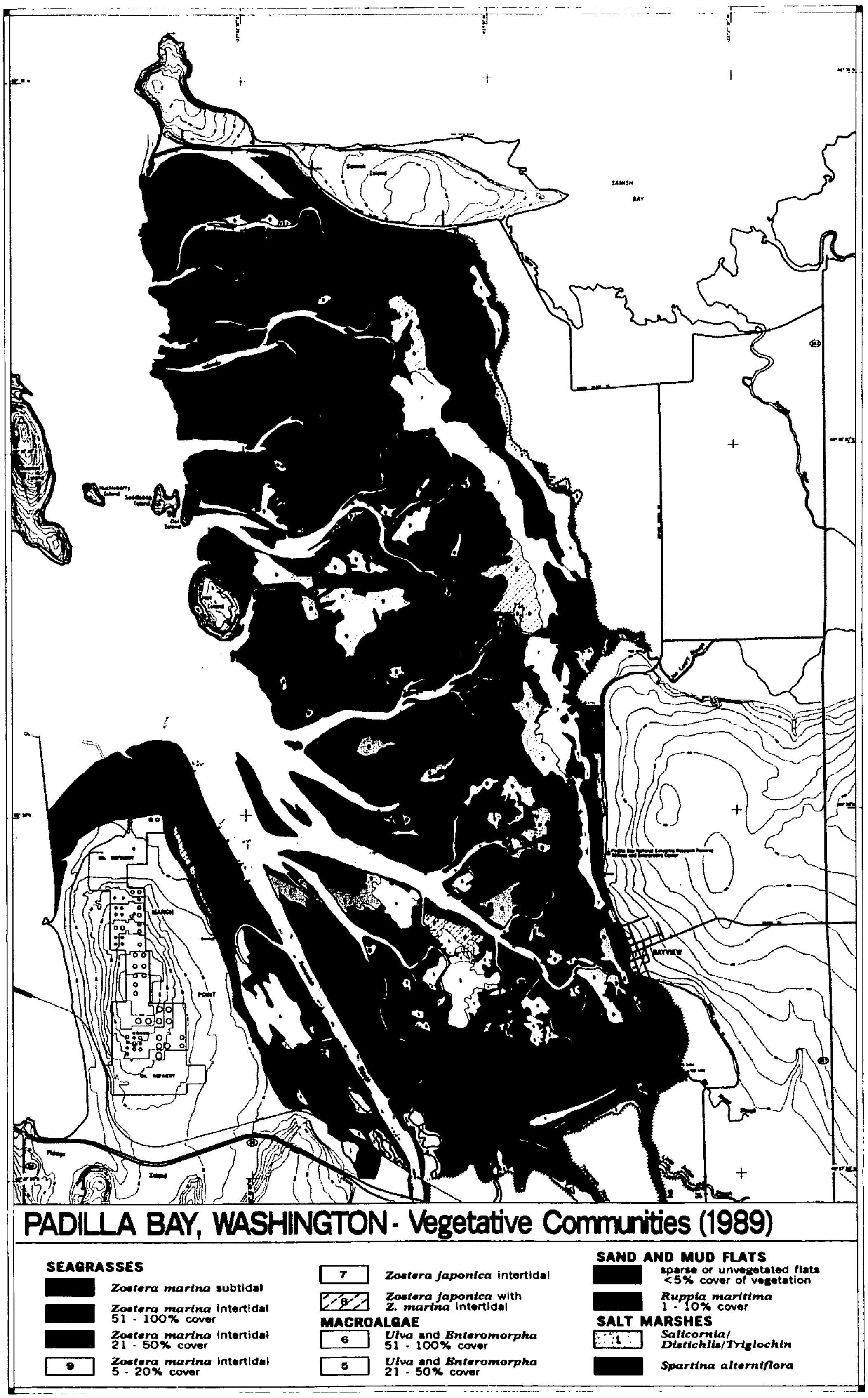

Figure 1. Distribution of habitats in Padilla Bay, Washington (after Bulthuis 1991)

Table 5
Area (in hectares) of Intertidal and Subtidal Eelgrass (*Zostera marina* and *Z. japonica*) in Five Sections of Padilla Bay in Midsummer in 1973, 1989, 1992, and 1993

Section	1973	1989	1992	1993
North	1,425	1,412	1,717	1,551
Bay View Ridge	1,515	1,435	1,510	1,472
South	586	171	168	134
March Point	204	190	181	181
Padilla Bay Total	3,730	3,208	3,576	3,338

Note: The 1989 data are from Bulthuis (1991); 1973, 1992, and 1993 data are from Bulthuis and Rogers (unpublished data). The five sections of the bay are from Bulthuis (1991) and are delineated in Figure 2.

Table 6
Aboveground Dry Weight and Density of Eelgrass and Algae During Summer at Various Locations in Padilla Bay in Eight Different Studies

	Aboveground Dry Weight, g m^{-2}			Density, no. m^{-2}	
Author-Site	*Z. marina*	*Z. japonica*	algae	*Z. marina*	*Z. japonica*
Smith and Webber 1978[a,b]					
+1 foot	140		5		
+2 foot	90		4		
+3 foot	70		3		
+4 foot	160		5		
Clark 1981					
Sand substrate		50-100			
Pebble substrate		<1-70			
Riggs 1983		163			
Webber, Mumford, and Eby 1987					
1	60	100		200	3,500
2	110	1		770	13
3	150		45	280	
4	140			85	
5	90			40	

(Continued)

[a] Wet weight converted to dry weight assuming ratio of 8:1. Annual mean reported.
[b] *Z. marina* and *Z. japonica* combined.
[c] Dry weight of algae is for epiphytes.

Table 6 (Concluded)					
	Aboveground Dry Weight, g m^{-2}			Density, no. m^{-2}	
Author-Site	*Z. marina*	*Z. japonica*	algae	*Z. marina*	*Z. japonica*
Thom 1990					
0.6 foot		140	<5[c]		3,200
0.1 foot	180		270[c]	800	
-0.4 foot	180		80[c]	300	
Thom, Miller, and Kennedy 1991					
ZJ		130	10[c]		
ZM1	90		9[c]		
ZM4	200		25[c]		
Bulthuis 1991					
1	100		180	250	
2	100		150	230	
3	60		130	440	
4	60		130	160	
5	30		40	180	
6	20		190	60	
7	12		40	160	
8[b]		29	8		390
9		31	<1		1,100
10	<1		530	6	
Bulthuis and Shaw 1993					
1-1992		130			3,900
1-1993		40			2,000
2-1992[b]	140			1,600	
2-1993[b]	180			1,300	
3-1992	160-340			190	

shore are better represented than sites farther from shore. The main intertidal beds of *Z. marina* in Padilla Bay occur in the lower intertidal, but few sites were sampled in those beds. However, Table 6 does indicate the ranges of biomass and density of *Z. marina* and *Z. japonica* that occur in Padilla Bay. Dry weight and density measurements for *Z. marina* are within the range reported for *Z. marina* populations in other parts of the world (McRoy and McMillan 1977; Zieman and Wetzel 1980) and similar to seasonal maxima reported for *Z. marina* in Puget Sound ((18-400 g m^{-2}; 160-610 shoots m^{-2}, Phillips 1972) (85 g m^{-2}, Thom and Albright 1990)). Similarly, the density and shoot biomass of *Z. japonica* is in the same range as other reports for *Z. japonica* in the Pacific Northwest (Harrison 1982b).

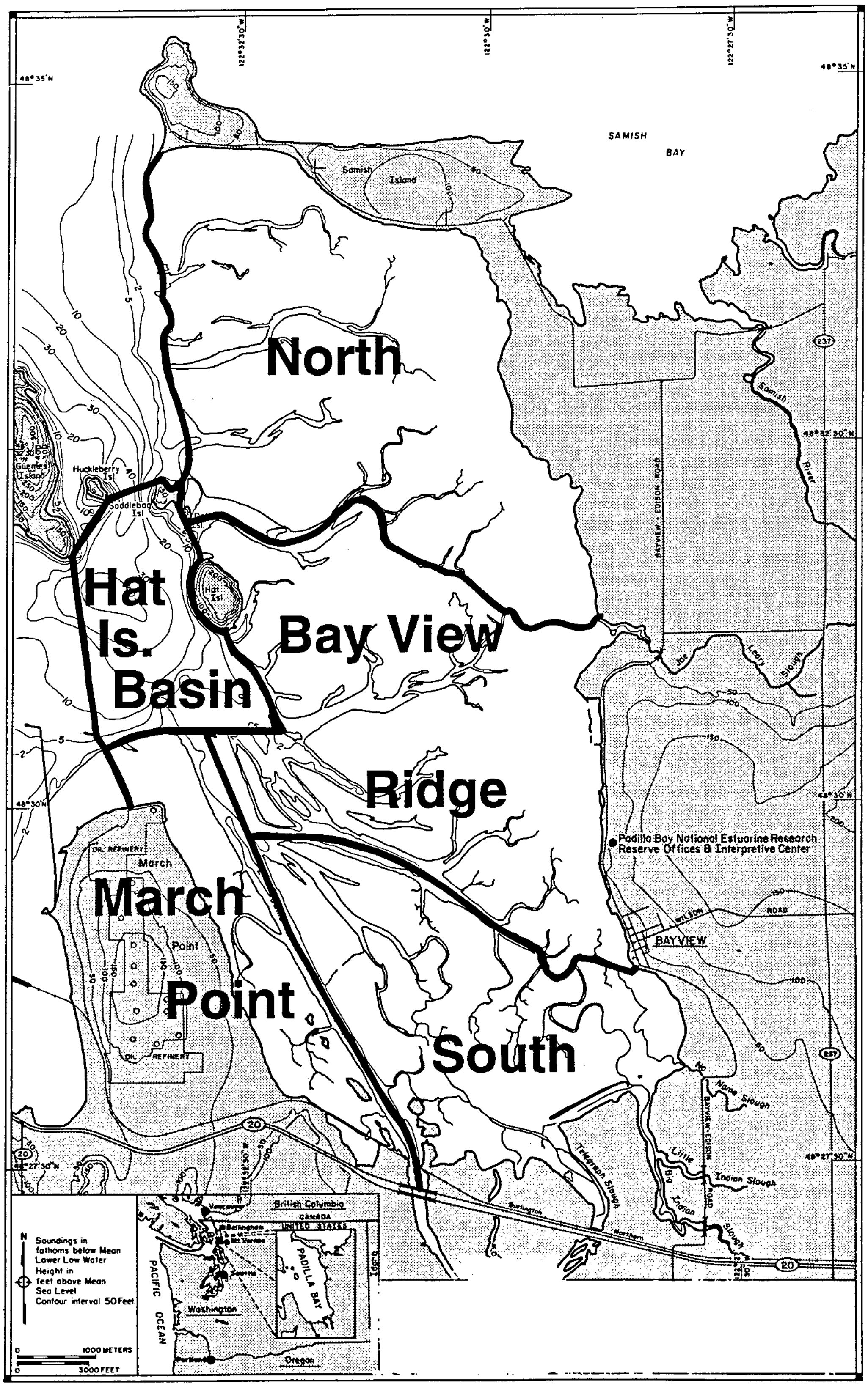

Figure 2. Sections of Padilla Bay in which the areal coverage of eelgrass habitat was grouped and estimated (Table 5) (after Bulthius 1991)

Seasonal variations in eelgrass

Seasonal changes in density and biomass of *Zostera* spp. in Padilla Bay have been studied by Thom (1990) and Thom, Miller, and Kennedy (1991). As for *Z. marina* at other temperate locations, biomass and density are generally higher during summer and lower during winter. *Zostera japonica* had a particularly strong seasonal fluctuation (density of 100 shoots m^{-2} in winter to 3,200 in summer, Thom 1990) and shoot biomass minima of less than 10 g dry wt m^{-2} compared with summer maxima of about 140 (Thom 1988, 1990). On the other hand, density of *Z. marina* approximately doubled at the two sites reported by Thom (1988, 1990): from 400 to 800 shoots m^{-2} and from 50 to 200 shoots m^{-2}. However, for one of the sites, the lowest observed density was in August, and for the other, it occurred in June. Shoot biomass of *Z. marina* fluctuated seasonally greater than did density. Winter minima were about 10 and 60 compared with spring/summer maxima of 180 and 280 g dry wt m^{-2} (Thom 1988, 1990). Thus, *Z. japonica* fluctuates strongly with the season, while *Z. marina* has a more stable density and biomass throughout the year, particularly at the lower elevations.

Primary productivity

The primary productivity of the eelgrass community (including epiphytic algae and benthic algae) was measured at several sites in Padilla Bay by Thom (1990) and total productivity in Padilla Bay estimated. Annual net primary productivity for the eelgrass system was estimated as 351 g C m^{-2} with *Z. japonica* contributing 2 percent, *Z. marina* 48 percent, and epiphytic algae 50 percent of the annual production. These rates indicate somewhat lower productivity of eelgrasses in Padilla Bay than values published for eelgrasses elsewhere (McRoy and McMillan 1977). Thom (1990) notes, for several reasons, that the estimates for Padilla Bay may be underestimates and suggests that actual eelgrass productivity may be three times greater than estimated in his study.

Nutrient sources for eelgrass

As rooted vascular plants, eelgrasses are able to absorb nutrients for growth and productivity both from the sediments via their roots (McRoy and Barsdate 1970; McRoy and Goering 1974) and from the water column through their leaves (Thursby and Harlin 1982). Williams and Ruckelshaus (1993) studied effects of nutrient enrichment of the water column and of the sediments on eelgrasses and epiphytes in Padilla Bay. Their studies indicated that eelgrasses in Padilla Bay are nitrogen limited and that during times of peak growth, the eelgrasses are taking up nutrients from the sediments in Padilla Bay. Their study also demonstrated the importance of grazing of the epiphytes on eelgrass leaves to prevent deleterious effects of high biomass of epiphytes on growth of eelgrass when water column nutrient concentrations are high. Thus, the eelgrasses in Padilla Bay are apparently nitrogen limited

and use the sediments as a source of nutrients to maintain their growth and productivity.

Eelgrasses and herbicides

Eelgrasses in estuaries may be threatened by a variety of pollutants and sources including herbicides and pesticides that are used for control of other plant species. Two studies conducted in Padilla Bay addressed the threat of herbicides to eelgrasses. Mayer and Elkins (1990) evaluated the threat to eelgrasses in Padilla Bay from herbicides and other pesticides applied to agricultural fields in the Padilla Bay watershed. For 2 consecutive years during the spring and early summer, the concentrations of the herbicides that were being applied that year were measured in the water and sediments in the freshwater sloughs draining the fields and in the water and sediments in Padilla Bay near the mouth of the sloughs. Only two herbicides, 2,4-D and Dicamba, were detected in any of the samples, and the concentrations of these two herbicides were so low in the water (<200 mg L^{-1} Dicamba and >2 mg L^{-1} 2,4-D) and sediments (<20 mg g^{-1} Dicamba) that Mayer and Elkins concluded that, "no ecologically significant levels of any of the fourteen pesticides studied were found in the water or sediments associated with Padilla Bay sloughs or the bay itself during this two-year investigation."

Bulthuis and Shaw (1993) and Bulthuis and Hartman (in a report to be published later) evaluated the effects of the herbicide glyphosate, mixed with a spreader, X-77, on eelgrass in Padilla Bay because of the anticipated use of glyphosate to control the introduced (to the Pacific Northwest) cordgrass, *Spartina alterniflora*. Bulthuis and Shaw reported that glyphosate had no consistent effect on *Zostera marina* or *Z. japonica* when sprayed directly onto eelgrasses in both an intertidal site and a subtidal site as measured by density, biomass, percent cover, dead leaves, or chlorophyll *a*. Similarly, Bulthuis and Hartman (in a report to be published later) reported no effect on the epiphytes of *Z. marina* or *Z. japonica* as measured by dry weight of epiphytes and by concentration of chlorophyll. Bulthuis and Shaw (1993) suggested that the glyphosate did not have any measurable effect because water retained on the leaf surface reduced absorption of the herbicide and because of the short time of exposure to the herbicide (3 hr or less) before the flooding tide.

Infauna

The only intensive sampling of the infauna of the intertidal eelgrass beds in Padilla Bay was conducted by Smith and Webber (1978) as part of the North Puget Sound Baseline Study Program. One of their sample sites was located in Padilla Bay where their sampling transect crossed sandy intertidal habitat and intertidal eelgrass habitat. Their sampling scheme emphasized substrate height (relative to tidal datum) and was reported as such. The data on fauna in their report cannot be separated into eelgrass sites and sandy sites. However, eelgrass biomass was reported from many of the reported tidal heights,

and the fauna reported are treated in this report as if they represent eelgrass habitat unless the distribution of the animal was restricted to the highest sampling heights where no eelgrass biomass was recorded. Both *Zostera marina* and *Z. japonica* (reported as *Zostera nana*) were reported present in the transect. In 1989, the area where the transect was taken was predominantly *Z. japonica* (Bulthuis, personal observation); therefore, the fauna reported by Smith and Webber (1978) probably represent fauna from intertidal eelgrass habitat of *Z. japonica*.

Bivalves were the major group of invertebrates reported by Smith and Webber, making up more than 50 percent of the biomass at all elevations sampled. The most common bivalve was the clam *Mya arenaria*, which was found both in the eelgrass and in the sandy habitat. Mean weight of *M. arenaria* was about 10 g, and density averaged one to three individuals/square meter at the two tidal heights with the highest density. *Macoma nasuta* was also very common, and the distribution data indicated that *M. nasuta* may be even more prevalent in the eelgrass areas than *M. arenaria*, occurring in densities up to 60 individuals m^{-2} with annual means of 3 to 15 at three sites. *Macoma balthica* and *Transennella tantilla* were also common in the tidal heights where eelgrass was prevalent. Common polychaetes included *Capitella capitata*, *Polydora* sp., *Polydora kempi-japonica*, *Abarenicola* sp., *Notomastus tenuis*, *Armandia brevis*, and *Glycinde picta*.

Riggs (1983) reported infauna sampled in June from a *Zostera japonica* community near Bay View State Park in Padilla Bay. Common species included the polychaetes *Cirriformia spirabranchia* and *Pseudopolydora kempi*, the amphipods *Allorchestes angusta*, *Corophium spinicorne*, and *Paraphoxus obtusidens*, the Tanaidacead *Pancolus californiensis*, the bivalve *Macoma nasuta*, and the gastropods *Nassarius fraticularis*, *Haminoea vesicula*, and *Battalaria attramentaria*.

Epifauna

The epifauna of the intertidal eelgrass habitat has been studied more intensively in Padilla Bay than the infauna. The eelgrass epifauna are diverse, abundant, and have a critical role in the food web. Simenstad et al. (1988) and Cordell and Simenstad (1988) studied the assemblage of epibenthic organisms in four habitats at three tidal stages during May 1986. Two were eelgrass habitats: intertidal *Zostera marina* and intertidal *Z. japonica*. Numerically abundant taxa were Nematoda, Harpacticoida, and Polychaeta in both habitats during tidal exposure (low tide, Tables 7 and 8). Total density of epibenthos at the benthic boundary layer was 2 to 3 orders of magnitude less during tidal submergence than densities collected during tidal inundation or tidal exposure (Simenstad et al. 1988, Tables 7 and 8). During all three tidal stages, harpacticoid copepods were the most abundant taxa in both *Z. marina* and *Z. japonica* except for tidal exposure in the *Z. japonica* when Nematoda were more abundant than Harpacticoida. Harpacticoid genera that were abundant on leaves of *Z. marina* included *Zaus*, *Harpacticus*, and *Tisbe*

Table 7
Density (number/square meter) and Standing Crop (in parentheses; milligrams/square meter) of Principal Epibenthos Taxa in *Zostera japonica* Habitat in Padilla Bay, May 1986, During Three Tidal Stages: Exposed, Tidal Front During Inundation, and Benthic Boundary Layer During Tidal Submergence

Taxa	Tidal Exposure	Tidal Front	Benthic Boundary Layer
Turbellaria	3,300 (330)		21 (2)
Nematoda	3,200,000 (8,000)	46,000 (670)	
Annelida Polychaeta	140,000 (14,000)		125 (6)
Oligochaeta	67,000 (2,700)		
Ostracoda	110,000 (3,700)	42,000 (780)	21 (2)
Copepoda nauplii			330 (6)
Calanoida		250,000 (7,400)	190 (6)
Harpacticoida	1,580,000 (27,000)	1,580,000 (27,000)	1,300 (50)
Poecilostomadoida		40,000 (1,300)	250 (4)
Tanaidacea	23,000 (26,000)		
Balanomorpha		5,600 (560)	190 (6)
Cumacea	140,000 (4,000)	72,000 (13,000)	42 (2)
Amphipoda Gammaridea	170,000 (44,000)	27,000 (5,000)	112 (17)
Caprellidea		2,200 (220)	
Decapoda		1,100 (110)	21 (2)
Insecta	57,000 (4,000)	7,800 (1,000)	
Total density (mean) (s.d.)	5,540,000 3,000,000	2,000,000 1,700,000	2,500 800
Total standing crop (mean) (s.d.)	110,000 19,000	42,000 24,000	110 10

Note: Data from Simenstad et al. (1988).

Table 8
Density (number/square meter) and Standing Crop (in parentheses; milligrams/square meter) of Principal Epibenthos Taxa in *Zostera marina* Habitat in Padilla Bay, May 1986, During Three Tidal Stages: Exposed, Tidal Front During Inundation, and Benthic Boundary Layer During Tidal Submergence

Taxa	Tidal Exposure	Tidal Front	Benthic Boundary Layer
Nematoda	1,800,000 (4,000)	7,800 (220)	190 (4)
Annelida Polychaeta	610,000 (51,000)		125 (6)
Oligochaeta	170,000 (27,333)		
Bivalvia	40,000 (18,000)		
Araneae	13,000 (670)		63 (4)
Ostracoda	6,700 (670)		150 (4)
Copepoda nauplii			440 (6)
Calanoida		2,200 (110)	270 (6)
Harpacticoida	2,720,000 (62,000)	2,720,000 (62,000)	13,000 (190)
Poecilostomatoida	6,700 (670)	8,900 (560)	(12)
Tanaidacea	87,000 (4,000)		
Balanomorpha			230 (6)
Cumacea	6,700 (1,300)	2,200 (330)	230 (14)
Amphipoda Gammaridea	13,000 (1,300)	3,300 (780)	100 (33)
Caprellidea	6,700 (670)	4,400 (330)	
Total density (mean) (s.d.)	 5,800,000 5,000,000	 830,000 520,000	 15,000 9,900
Total standing crop (mean) (s.d.)	 188,000 27,000	 12,000 4,900	 300 130

Note: Data from Simenstad et al. (1988).

(Simenstad et al. 1988). Density of harpacticoids increased along *Z. marina* leaf blades from the distal end and toward the rhizome end, with up to 23 species of harpacticoid copepods and densities greater than 2,000 per 100 cm^2 in the section of the leaf blade closest to the rhizome.

An important component of the eelgrass habitat is the epiphyte community on the leaves of the eelgrass. Simenstad et al. (1988) reported a range of 3 to 57 different taxa per 100 cm^2 of leaf area, mean standing crops of epibenthos up to 10,000 mg 100 cm^{-2} and mean density more than 140,000 100 cm^{-2} of leaf area (Table 9). Nematoda and Harpacticoida were particularly abundant. Caine (1991) measured abundance of the epiphytic amphipod *Caprella laeviuscula* in 3 months during spring. Density of *C. laeviuscula* averaged about 95 individuals per 625-cm^2 quadrats during March and April and then declined to about 1 per 625 cm^2 by mid June. Caine suggested that reproductive migrations of shiner perch, *Cymatogaster aggregata*, that move into the seagrass beds may selectively prey on caprellids and may be responsible for the sharp drop in caprellid abundance.

Common epifauna reported by Smith and Webber (1978) at tidal heights that included eelgrass were the snail *Batillaria attramentaria* and amphipods including *Anisogammarus confervicolus*, *Parallorchestes orchotensis*, and *Corophium* sp. Riggs (1983) also reported *Batillaria attramentaria* from a *Zostera japonica* site, but very few other species were found in the leaf samples, whereas many species were reported in leaf samples of *Z. marina* from Anacortes. Williams and Ruckelshaus (1993) reported high densities of the isopod *Idotea resecata* as well as the presence of *Lacuna* sp., *Phyllaplysia taylori*, and *Haminoea* spp. Thom, Miller, and Kennedy (1991) reported that the primary invertebrate grazers on the epiphyte community in the eelgrass habitat were *Idotea resecata*, *Caprella laeviuscula*, and *Lacuna variegata*. Abundance of these three grazers was monitored from October 1989 to July 1990 at three eelgrass sites. The variance was high when mean population density peaked, but both *Idotea resecata* and *Caprella laeviuscula* increased sharply in July compared with the rest of the year at two of the three sites while density of *Lacuna variegata* decreased (Thom, Miller, and Kennedy 1991). At the third site a similar seasonal pattern in density was evident, except that in addition to the observed peak in abundance in July, *Idotea resecata* had high population numbers in December and *Caprela laeviuscula* had high numbers in July.

The crab, *Cancer magister*, is another important component of the epifaunal community in eelgrasses in Padilla Bay. After megalopae of *C. magister* molt into juveniles (April-August in Washington and British Columbia, Pauley, Armstrong, and Heun 1986), they are found in shallow coastal waters including Padilla Bay. Juveniles settling in Padilla Bay may come both from oceanic cohorts and Puget Sound cohorts with about half coming from each cohort during 1988 (Dinnel, Armstrong, and McMillan 1993, Figure 3). The early instars are found primarily in intertidal eelgrass habitat or intertidal *Ulva* habitat (Dinnel et al. 1986). The eelgrass habitat apparently provides protection, substrate, and food organisms for the early

Table 9
Mean Density (number 100 cm^{-2} of blade surface) and Standing Crop (in parentheses: milligram 100 cm^{-2}) of Principal Epibenthos Taxa Collected on 10-cm Segments of Two (low and high epiphyte load) *Z. marina* Plants in Padilla Bay, Washington, May 1986

	Plants	
Taxa	#1, Low Epiphyte	#2, High Epiphyte
Foraminifera	620 (6)	
Hydroida		21 (6)
Turbellaria	650 (15)	620 (23)
Nemertea		139 (500)
Nematoda	5,400 (49)	80,000 (400)
Annelida Polychaeta	800 (820)	2,200 (580)
Oligochaeta	370 (110)	420 (500)
Gastropoda	33 (10)	170 (175)
Araneae	1,200 (5)	38 (4)
Ostracoda	1,100 (46)	3,800 (91)
Copepoda Calanoida	62 (6)	220 (14)
Harpacticoida	22,000 (580)	57,000 (1,100)
Poecilostomatoida	210 (15)	270 (22)
Cumacea	62 (6)	280 (15)
Tanaidacea		720 (391)
Isopoda	62 (6)	

(Continued)

Note: From Simenstad et al. (1988).

Table 9 (Concluded)		
	Plants	
Taxa	#1, Low Epiphyte	#2, High Epiphyte
Amphipoda Gammaridea	1,900 (2,900)	1,300 (6,200)
Caprellidea		7 (<1)
Unidentified egg case	150 (9)	
Density (mean) (s.d.)	35,000 47,100	147,000 337,000
Standing crop (mean) (s.d.)	4,620 9,000	9,950 26,300
Number taxa categories (mean) (s.d.)	14.8 3-53	29.9 16-57

instars (Pauley, Armstrong, and Heún 1986; McMillan 1991). The 1+ age class of juveniles prefer the shallow channels and subtidal eelgrass habitat rather than the intertidal habitat (Dinnel et al. 1986; McMillan 1991).

Fish

The fish community of the intertidal eelgrass habitat is generally transient with diurnal movement of fish onto and off the intertidal flats with the movement of tides, seasonal changes in the abundance of various species (Fresh 1979), and movements into and out of eelgrass habitats at different stages of the life cycle and growth (Fresh 1979; Simenstad et al. 1988; Caine 1991). In summarizing a 2-year study of fish assemblages at 15 sites grouped into five different habitat types in nearshore waters of northern Puget Sound, Fresh (1979) found that "the dominant nearshore pelagic species were present throughout the various nearshore habitats [including eelgrass habitat] of northern Puget Sound with little evidence of distinct assemblages in different habitats. However, even though the dominant species exploit the entire nearshore spectrum of habitats, there were preferred habitats and areas." Thus, there does not appear to be a distinct eelgrass habitat assemblage of fish, although many of the dominant species utilize the eelgrass habitat. One of the sample sites used by Fresh (1979) was an eelgrass habitat site in Padilla Bay. Biologically important species in Padilla Bay included Pacific herring, threespine stickleback, Pacific sand lance, surf smelt, longfin smelt, soft sculpin, Chinook salmon, and staghorn sculpin.

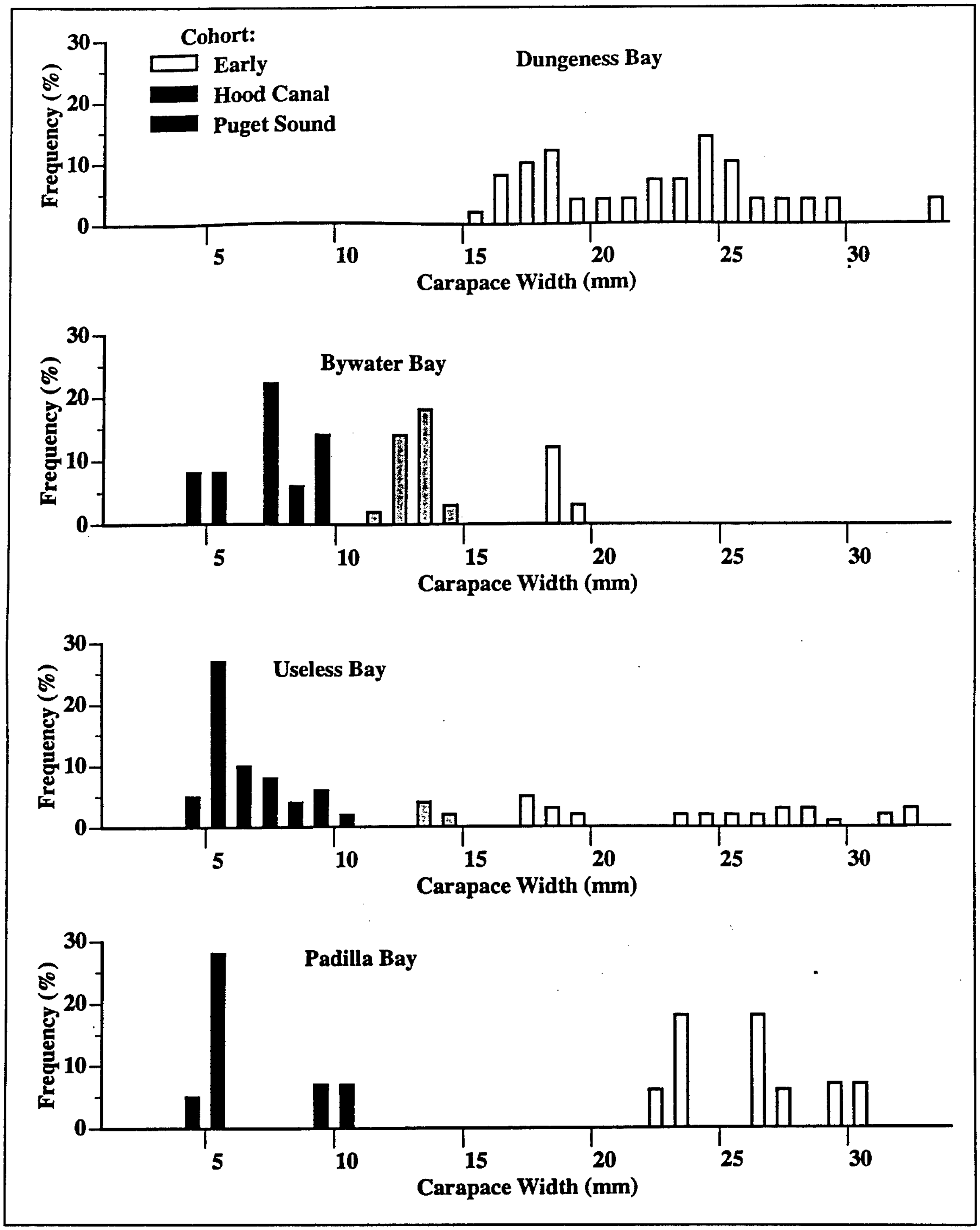

Figure 3. Size-frequency distributions (SFDs) of 1988 year-class crabs, *Cancer magister*, sampled intertidally in late August 1988 at Dungeness Bay, Bywater Bay (Hood Canal), Useless Bay, and Padilla Bay (SFDs are broken down by cohort contribution for each area, as indicated by histogram shading) (after Dinnel, Armstrong, and McMillan 1993)

Dinnel et al. (1990) caught fish in Padilla Bay in the intertidal eelgrass, subtidal eelgrass, and subtidal channel habitats. Fish species with abundances greater than 100/ha in the intertidal eelgrass included staghorn sculpin, snake prickleback, silver-spotted sculpin, shiner perch, saddleback gunnel, three-spined stickleback, and bay pipefish. All of these species, except for the first two, were found almost exclusively in the two eelgrass habitats and only in very low numbers in the channel habitat (Figure 4). The staghorn sculpin, the most abundant of the fish sampled in this study, fed about equally on amphipods, crabs, unidentified crustaceans, and isopods in the intertidal eelgrass habitat (Dinnel et al. 1990).

Pacific herring are abundant throughout Puget Sound and were abundant in two net samples in Padilla Bay (Fresh 1979; Miller et al. 1977). Herring lay adhesive eggs on intertidal and subtidal marine vegetation, and Washington State Department of Fisheries and other agencies survey eelgrass beds for presence and density of herring spawn. Surveys of herring spawn in the vicinity of Padilla Bay have indicated spawn occasionally present in Padilla Bay (Trumble et al. 1977), but medium to heavy spawning areas are more regularly reported from both sides of March Point and in Fidalgo Bay than in Padilla Bay (Pentilla 1984, 1985).

Birds

The intertidal eelgrass community in Padilla Bay directly and indirectly supports an abundant avifauna. Study of the avifauna, however, is limited to periodic counts of the waterfowl in the bay and some study of brant, *Branta bernicla*, populations. Brant are herbivores that feed on eelgrass, breed in the Canadian and Alaskan arctic, and winter along the Pacific coast of the United States and Mexico (Reed, Davison, and Kraege 1989). Few brant now overwinter north of the U.S.-Mexico border, but one of the remaining important overwintering sites is Padilla Bay (Jeffrey 1976; Reed, Davison, and Kraege 1989). Brant begin arriving in Padilla Bay in November and may be present as late as June (Reed, Davison, and Kruege 1989). Jeffrey (1976) reported average numbers of brant for each month from October through April for the years 1970-1976 (Table 10). Spring migration swells the number of these geese on Padilla Bay to a maximum in April for the months when counts were made. During the 1987-1988 winter, Reed, Davison, and Kraege (1989) estimated that about 15,000 brant were overwintering in Padilla Bay (Table 11). On the basis of different color phases and examination of leg-ringed geese, they suggested that most of the High Arctic brant overwinter in Padilla Bay (Reed, Davison, and Kraege 1989).

Jeffrey (1976) summarized the periodic counts of dabbling ducks present in Padilla Bay during autumn and winter (Table 12). About 10,000 each of wigeon and pintail are present in Padilla Bay during these months with about half as many mallard and green-winged teal. No habitat studies have been conducted in Padilla Bay, but Baldwin and Lovvorn (1992, unpublished manuscript) reported in Boundary Bay (located about 70 km north of Padilla Bay)

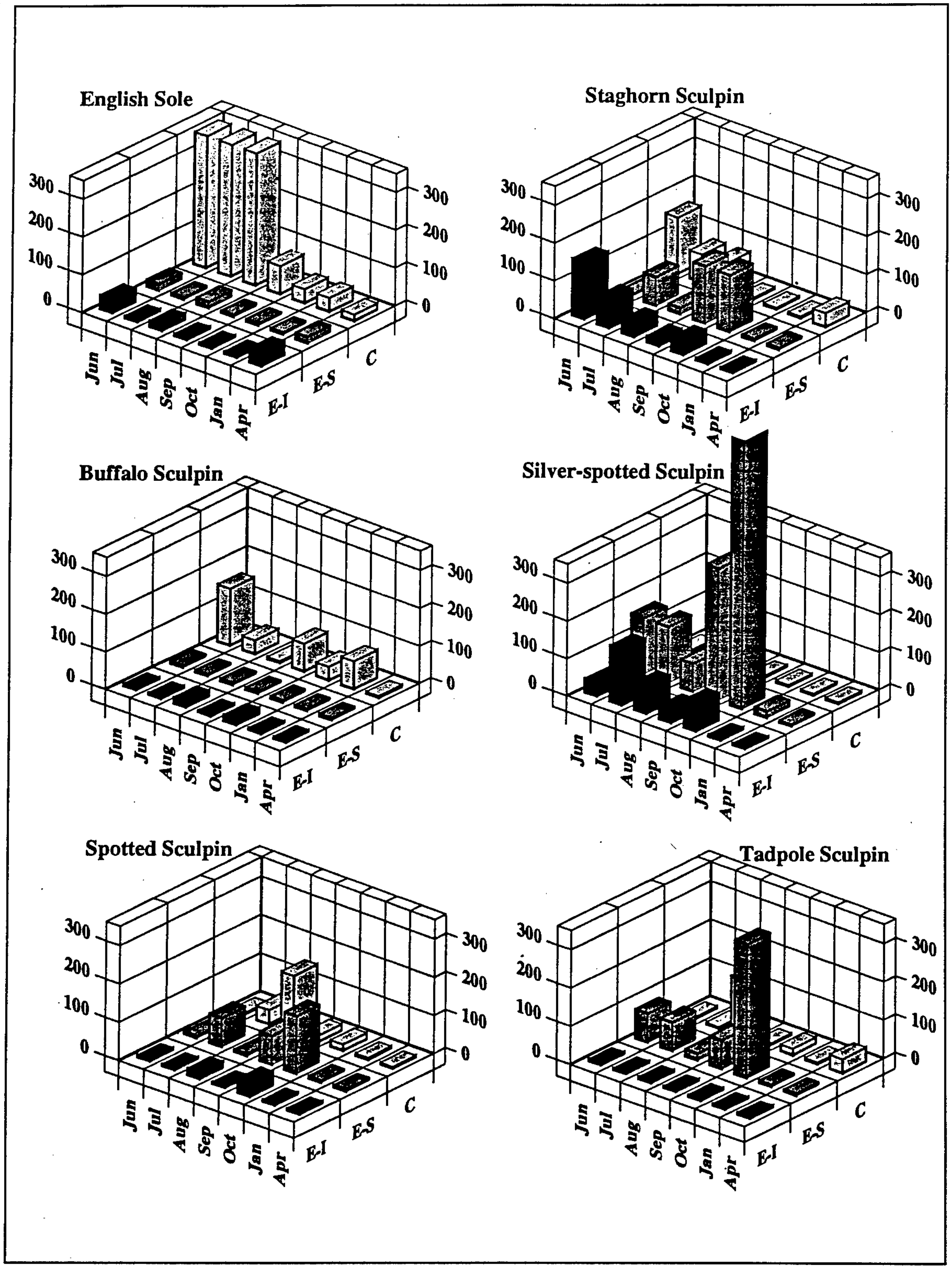

Figure 4. Fish density (fish/hectare) during 7 months (between June 1987 and April 1988) by habitat (E-I = Intertidal eelgrass; E-S = Subtidal eelgrass; C = Channels) of the 12 most common fish species caught in beam trawl tows (after Dinnel et al. 1990) (Continued)

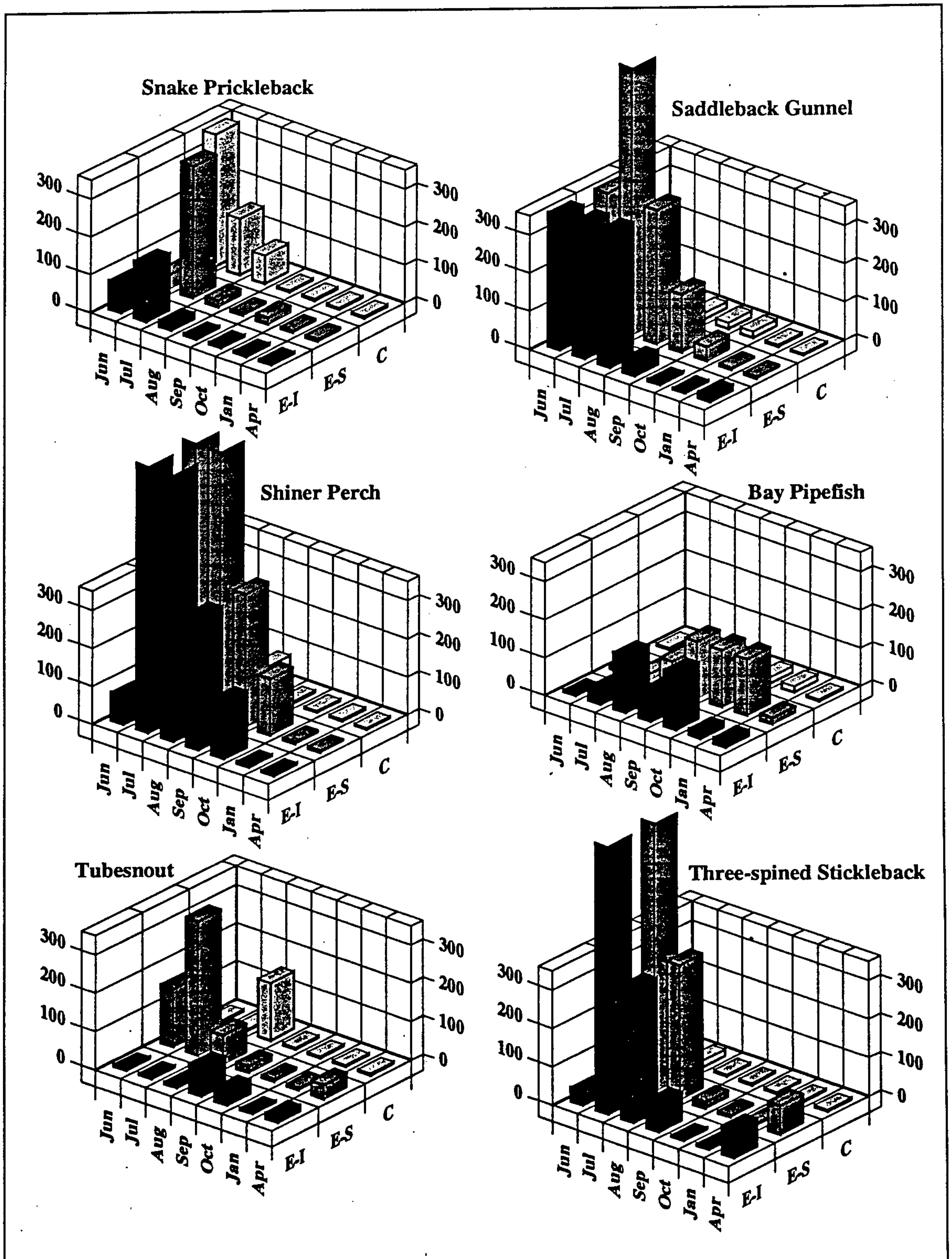

Figure 4. (Concluded)

Table 10
Mean Number of Brant in Padilla Bay Each Month From October to April Based on Weekly to Monthly Counts Made During 1970-1976 by Washington Department of Wildlife

Month	Mean Number of Brant
October	250
November	1,720
December	2,970
January	2,830
February	1,650
March	4,090
April	28,250

Note: Data from Jeffrey 1976.

Table 11
Numbers of Brant Recorded in Padilla Bay During Aerial Surveys Conducted Between November 1987 and February 1988

Date of Survey	Number of Brant
17 November	4,990
4 December	16,290
18 December	14,450
24 December	16,110
4 January	15,320
4 February	18,120
25 February	19,800

Note: From Reed, Davison, and Kraege (1989).

Table 12
Mean Estimates of Number of Four Species of Dabbling Ducks in Padilla Bay From 1966 to 1975

Month	Mallard	Pintail	Green-Winged Teal	Wigeon	Total
October	2,760	10,530	4,670	9,290	27,250
November	3,910	7,560	3,000	13,540	28,010
December	5,940	10,570	3,040	16,810	36,360
January	2,950	4,150	1,430	8,456	16,980

Note: From Jeffrey 1976.

that these dabbling ducks were feeding mainly in eelgrass habitats. Their diet consisted of eelgrass and animals associated with eelgrass communities.

Food webs and energy flow

Eelgrass habitats are considered to be primarily detritus-based ecosystems with the bulk of the eelgrass productivity becoming leaf detritus that is either entrapped in situ or else exported from the system to adjacent open-water areas or to shores and beaches (Klug 1980; Harrison 1989; Hemminga and Nieuwenhuize 1991). This may be particularly true of the intertidal eelgrass habitat where semidiurnal tides may move broken leaves and dislodged plants either to channels and out to deeper waters or up onto the beaches. No studies in Padilla Bay have attempted to quantify such export of plant production from the bay. However, Ruckelshaus, Wissmar, and Simenstad (1993) estimated food sources for filter-feeding mussels in four habitats in Padilla Bay: slough, mud flat, eelgrass, and neritic. In spite of Padilla Bay being a "well-mixed" estuary, they found differences in local seston composition and mussel growth rates and suggested that such differences reflect in part the heterogeneous distribution of benthic primary-producer habitats in Padilla Bay (Wissmar 1986; Ruckelshaus 1988; Ruckelshaus, Wissmar, and Simenstad 1988, 1990, 1993). Eelgrasses were a major source of the seston for mussels growing above intertidal eelgrasses.

Studies by Thom, Miller, and Kennedy (1991) have indicated the importance of grazing in the eelgrass ecosystem in Padilla Bay. In particular, the high density of *Idotea resecata* combined with their estimated grazing rate indicates that *I. resecata* may graze 20 percent of the estimated annual production of the eelgrass ecosystem (Thom, Miller, and Kennedy 1991, Table 13)

Table 13
Annual Grazing Estimates for *Idotea* and Birds in Eelgrass System

	Net Primary Productivity		
Idotea	gC m^{-2}	Total ($\times 10^3$ kgC)	Percent of Total
Z. japonica	246.4	1,185	374[a]
Z. marina	38.2	964	9.4[b]
Total *Idotea*	--	2,149	20.4
Mallard	1.322	40	0.4
Northern pintail	1.310	40	0.4
American widgeon	1.218	37	0.4
Green-winged Teal	0.083	2	<0.1
Black brant	1.320	40	0.4
Total Birds	5.253	159	1.5
Total grazed	--	2,308	21.9

Note: From Thom, Miller, and Kennedy 1991.
[a] *Z. japonica* subsystem only.
[b] *Z. marina* subsystem only.

and in intertidal *Z. japonica* habitats may graze the total annual production. In contrast, grazing by birds is estimated to account for only 1.5 percent of the total seagrass productivity. Other important grazers studied by Thom, Miller, and Kennedy were the snail *Lacuna variegata* and the amphipod *Caprella laeviuscula*. Other amphipods are also important grazers of epiphytes.

The invertebrate grazers are an important food source for fish in the bay. Shiner perch, *Cymatogaster aggregata*, appear to selectively feed on caprellid amphipods when they are available and only after the abundance of caprellids decreases, switch to other prey items (Caine 1991). Amphipods and isopods were the most important prey item for five of the six most common marine fish caught by Dinnel et al. (1990) in Padilla Bay (Table 14). Harpacticoid copepods were the most important prey item for surf smelt, Pacific sand lance, chum salmon, and threespine stickleback caught by Simenstad et al. (1988) in Padilla Bay (Table 15). These studies indicate that in Padilla Bay, energy is transferred from the eelgrass community to carnivores by way of grazers as well as through the detritus food chain.

Table 14
Percent Indices of Relative Importance for Six Common Marine Fish Caught by Beam Trawl in Padilla Bay

Group	Staghorn Sculpin (n = 160 fish)	Silverspotted Sculpin (n = 22 fish)	Great Sculpin (n = 13 fish)	Padded Sculpin (n = 12 fish)	Whitespotted Greeling (n = 12 fish)	Saddleback Gunnel (n = 10 fish)
Amphipod	42.8	90.1	9.1	96.9	18.9	82.3
Isopod	17.8	9.6	29.2	0.0	68.2	16.4
Crab	14.0	0.1	1.0	0.3	3.1	0.0
Shrimp	3.1	0.2	13.0	0.0	6.3	0.0
Other crustacean	3.5	0.0	0.0	2.6	0.1	1.0
Mollusc	2.3	0.0	1.9	0.0	0.6	0.1
Polychaete	8.7	0.0	0.0	0.2	2.8	0.2
Fish	1.1	0.0	43.8	0.0	0.0	0.0
Algae, detritus, etc.	6.7	0.0	2.0	0.0	0.0	0.0

Note: From Dinnel et al. 1990.

Staghorn sculpin, *Leptocottus armatus*, in Padilla Bay shift their food preference as they increase in size (Pantalone 1985). The smallest size classes of staghorn sculpins feed primarily on harpacticoid copepods, shifting to gammarid amphipods at size 70 mm and above except for two size classes for which polychaetes were the most important prey item.

Table 15
Percent Indices of Relative Importance for Five Species of Fish Caught in Padilla Bay in May 1986

Group	Surf Smelt	Pacific Herring	Pacific Sand Lance	Chum Salmon	Threespine Stickleback
Polychaeta	5.2				0.1
Calanoida		0.2	3.5	4.4	0.3
Harpacticoida	86.3	37.0	92.6	83.2	50.7
Poecilostomatioda			0.2		0.2
Balanomorpha		0.1	1.1	0.1	0.1
Cumacea	1.4		0.2		
Gammaridea	6.5	1.1	1.2	9.8	48.6
Caprellidea					0.1
Euphausiacea				0.5	
Decapoda		61.6	1.1	2.1	

Note: Data extracted from Simenstad et al. 1988.

The food web of the eelgrass community is complex, in part, because of the diverse and abundant organisms that are present in the community. In addition, juvenile stages may shift their prey items as they grow in size or change life cycle stage. Simenstad et al. (1979) summarized the shallow sub-littoral food web of a protected mud/eelgrass habitat (including sample sites in Padilla Bay) (Figure 5). The food web of the intertidal eelgrass would be expected to be similar since some of the sampling on which the food web is based was from intertidal eelgrass sites.

Subtidal Aquatic Bed: Rooted Vascular

The subtidal eelgrass habitat in Padilla Bay is located along the channel margins and along the edges of the intertidal eelgrass flats (Figure 1). Thus, subtidal eelgrass patches tend to be linear, bordered on one side by intertidal eelgrass and on the other side by subtidal sand habitat. The approximate area of subtidal eelgrass in Padilla Bay is 250 ha (Table 4).

The subtidal eelgrass is delineated from the intertidal eelgrass by extreme low-water depth (Dethier 1990; Ray 1994). This depth is used to divide the intertidal from the subtidal because the ability to survive even short periods of exposure to the air (that is a few times during the year) is an important characteristic dividing whole groups of species into those that can live in the intertidal habitat from those that cannot. However, in Padilla Bay (and many

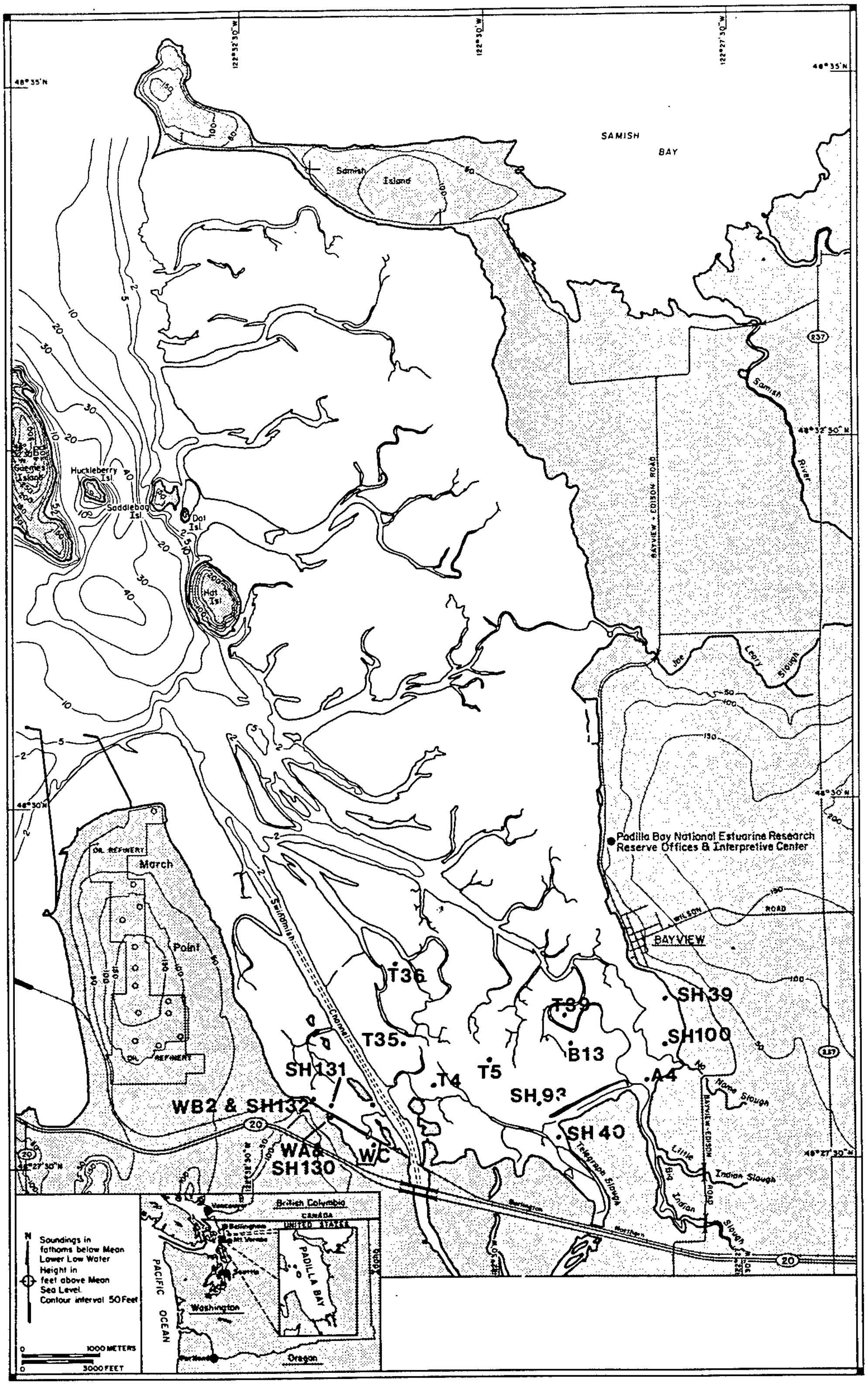

Figure 5. Sample sites in Padilla Bay at which sediment particle size was greater than 50-percent mud. References to site locations in Table 20

similar bays with broad intertidal expanses of seagrasses), the exact depth relative to tidal datum is much less important than the microtopography and the ability of seagrasses to retard water flow. Much of the broad intertidal eelgrass flats retain some water during low tides, even during extreme low-water spring tides (Bulthuis and Shaw 1993, unpublished data). Similar phenomena of water trapping have been described in *Thalassia testudinum* with a greater depth of water retained where the biomass of seagrasses was greater (Powell and Schaffner 1991). Thus, biota that cannot survive exposure to air for even a short period of time are able to survive (and thrive) in the intertidal eelgrass beds that are well above extreme spring low-water depth. Because of this phenomenon, the distinction between the intertidal and subtidal eelgrass habitats is blurred. Most of the studies of eelgrass communities in Padilla Bay were conducted on intertidal beds in which the eelgrasses were never fully exposed to the air. Therefore, the descriptions and summary of studies in the intertidal eelgrass habitat apply also to the subtidal eelgrass habitat. In the following discussion, the review will be confined to studies that were explicitly sampled in the subtidal eelgrass habitat and some comparison made with the intertidal habitat.

The subtidal seagrass beds are more difficult to detect and map with remote sensing techniques. Satellite imagery was unable to distinguish the subtidal eelgrass beds from deep water in Padilla Bay (Webber, Mumford, and Eby 1987). Bulthuis (1991) used color aerial photography to delineate some of the subtidal eelgrasses, but in some areas, SCUBA diving was required to locate the lower limit of distribution. The shoot biomass of eelgrass increased with increasing depth in a study by Thom (1990), although the deepest site was not below -1.2 m, the extreme lower tide depth in Padilla Bay. If the pattern observed by Thom (1990) continues into the subtidal, the shoot biomass of eelgrass is likely to be higher than in the intertidal. The only reported data on biomass of subtidal eelgrass in Padilla Bay were collected by students and staff of Huxley College and reported in Jeffrey (1976). Mean biomass of eelgrass was 24.7 g in 0.25 m^2 ($\sim$100 g m^{-2}) in August and 5.9 g (24 g m^{-2}) in December.

The invertebrate community of the subtidal eelgrass would be expected to be similar to the intertidal eelgrass. Jeffrey (1976) lists 36 species with a wet weight biomass greater than 0.1 g 0.25 m^{-2} (Tables 16 and 17) and reported a total of 133 species found at one subtidal eelgrass site. Caine (1991) reported that the density of caprellid amphipods was similar in the subtidal eelgrass along the channel edge to the densities in the intertidal flats, with populations in both habitats declining drastically when migrating shiner perch, *Cymatogaster aggregata*, entered Padilla Bay. Young-of-the-year Dungeness crabs, *Cancer magister*, are found primarily in the intertidal eelgrass habitat. However, as they grow and mature, the larger crabs move to the subtidal eelgrass beds and into the eelgrass-covered channel bottoms (Dinnel et al. 1986; McMillan 1991). As they continue to mature, they move out of the subtidal eelgrass and into the deeper channels. Thus, the subtidal eelgrass provides habitat for a short stage in the life cycle of Dungeness crabs in

Table 16
Infauna >2 mm With Mean Wet Weight (± standard deviation, n = 8 in August, 10 in December) in a Subtidal *Zostera marina* Habitat (depth = -6 ft MLLW) Sampled by Huxley College Classes and Reported by Jeffrey (1976)

Species	August	December
Hydrozoa		
Obelia sp.	0.1 ±0.3	0
Nemertea		
Cerebratulus californiensis	0.6 ±1.8	0
Paranemertes peregrina	0.2 ±0.4	0
Mollusca		
Macoma sp.	0.4 ±0.3	0.5 ±0.4
Macoma nasuta	1.1 ±2.1	1.3 ±2.7
Mya arenaria	0.4 ±0.5	+ +
Protothaca sp.	0.2 ±0.2	0.3 ±0.2
Transennella tantilla	0.5 ±0.2	0.9 ±0.3
Polychaetes		
Mediomastus sp.	+ +	0.5 ±0.3
Nephtys sp.	0.1 ±0.4	0.2 ±0.6
Nereis sp.	0.3 ±0.1	0.2 ±0.2
Haploscoloplos elongatus	0.2 ±0.2	0.1 ±0.1
Owenia fusiformis	1.5 ±0.4	1.3 ±0.6
Harmothoe imbricata	0.2 ±0.3	+ +
Prionospio pinnata	0.2 ±0.1	0.1 ±0.1
Isopoda		
Synidotea bicuspida	1.1 ±0.7	0.4 ±0.3
Amphipoda		
Gammarid amphipods	0.2 ±0.3	0.2 ±0.1
Decapoda		
Cancer magister	0	3.4 ±108.0
Echinodermata		
Leptasterias hexactis	+ +	0.1 ±0.2
Ophiuroidea sp.	1.1 ±0.5	0.3 ±0.2
Leptosynapta sp.	0.4 ±0.3	0.3 ±0.2

Note: Cores 0.05 m^2 and 15 cm deep were taken August 13 and December 1, 1975.
Only species with mean wet weights greater than 0.1 g are reported.
+ Indicates presence <0.1 g wet weight.

Padilla Bay, although some crabs of all age classes are found in this habitat at some time (Dinnel et al. 1986; McMillan 1991).

Studies of the fish assemblages in Padilla Bay have often included sampling over subtidal eelgrass habitat, in part, because of the ease of sampling compared with the intertidal flats. However, most sampling gear and techniques cover a large area and typically sample more than one habitat type. The fish and prey reported by Simenstad et al. (1988) appear to have been caught over eelgrass areas that included both intertidal and subtidal habitats (Table 18),

Table 17
Epifauna 30 mm With Mean Wet Weight (± standard deviation, n = 8 in August, 10 in December) in a Subtidal *Zostera marina* Habitat (depth = -6 ft MLLW) Sampled by Huxley College Classes and Reported by Jeffrey (1976)

Species	August	December
Eelgrass (dry wt.)		
Zostera marina	24.7 ±8.3	5.9 ±2.9
Algae (wet wt.)		
Botryoglossum farlowianum	0 ±0	0.2 ±0.7
Monostroma fuscum	48.3 ±17.7	0.5 ±0.8
Urospora sp.	0.2 ±0.3	+ +
Epifauna (wet wt.)		
Hydrozoa		
Obelia sp.	0.7 ±0.4	0
Anthozoa		
Epiactis prolifera	0.9 ±1.7	+ +
Mollusca		
Lacuna sp.	0.3 ±0.3	+ +
Unknown Doridacea	0 0	0.2 ±0.1
Polychaetes		
Platynereis bicanaliculata	0.3 ±0.3	+ +
Harmothoe imbricata	0.4 ±0.6	0
Isopoda		
Synidotea bicuspida	8.7 ±4.9	0.5 ±0.3
Amphipoda		
Metacaprella kennerlyi	1.2 ±0.6	1.8 ±0.8
Gammarid amphipods	0.4 ±0.2	0.1 ±0.1
Bryozoa		
Unknown Bryozoa	0.2 ±0.1	0
Echinodermata		
Leptasterias hexactis	2.2 ±3.1	3.7 ±4.4

Note: Quadrats 0.25 m^2 were taken August 13 and December 1, 1975. Only species with mean wet weights greater than 0.1 g are reported.
\+ Indicates presence <0.1 g wet weight.

including the five species for which stomach contents were analyzed: surf smelt, Pacific herring, Pacific sand lance, chum salmon, and threespine stickleback (Table 15). Dinnel et al. (1990) sampled fish in three habitats: intertidal eelgrass, subtidal eelgrass, and subtidal channel. In the subtidal eelgrass habitat, the estimated density of staghorn sculpin, tadpole sculpin, silver-spotted sculpin, shiner perch, saddleback gunnel, snake prickleback, three-spined stickleback, tubesnout, and bay pipefish exceeded 100 fish per acre at least some time during the year (Figure 4). Other species, such as buffalo sculpin and English sole are abundant in the adjacent channel habitat,

Table 18
List of Fish Species Caught in Beach Seine and Purse Seine in Padilla Bay, May 9, 1986

Scientific Name	Life History Stages[a]	Common Name
Family Clupeidae		
Clupea harengus pallasi	J	Pacific herring
Family Salmonidae		
Oncorhynchus keta	J	Chum salmon
Family Osmeridae		
Hypomesus pretiosus	J, A	Surf smelt
Family Gasterosteidae		
Gasterosteus aculeatus	J, A	Threespine stickleback
Family Syngnathidae		
Syngnathus leptorhynchus	J	Bay pipefish
Family Ammodytidae		
Ammodytes hexapterus	J	Pacific sand lance
Family Pleuronectidae		
Lepidopsetta bilineata	J	Rock sole
Pleuronectes (Platichthys stellatus)	J	Starry flounder
Pleuronectes (Parophrys) vetulus	J	English sole
Psettichthys melanostictus	J	Sand sole

Note: From Simenstad et al. 1988.
[a] J = juvenile; A = Adult.

but are rare in the subtidal eelgrass. Diets of these fish were considered in the section on intertidal eelgrass, and data are presented in Tables 14 and 15.

Intertidal Aquatic Bed: Algal

The extensive intertidal flats in Padilla Bay include areas that are covered with macroalgae. Two hundred twenty hectares of intertidal flats were so covered in 1989 (Bulthuis 1991, Table 4, Figure 1). Most of the algal biomass was *Ulva* sp. and *Enteromorpha* sp., but other common genera were *Laminaria*, *Ceramium*, *Gracilaria*, and *Fucus*. The cover of macrolagae within such identified habitats varied from 20- to 100-percent cover. At one 1-ha site with 80- to 100-percent cover, Bulthuis (1991) reported a mean algal biomass of 530 g dry weight m^{-2}, primarily *Ulva* sp. and *Enteromorpha* sp. The sediment surface beneath these algal mats was anaerobic at some spots. These algal mats are transitory both seasonally, with a maximum biomass in spring or summer, and between years, with high interannual variability (Riggs unpublished data, Bulthuis unpublished data).

The only study of fauna associated with algae in Padilla Bay dealt with Dungeness crabs, *Cancer magister* (Dinnel et al. 1986; McMillan 1991; McMillan et al., unpublished manuscript). They reported the highest density of young-of-the-year crabs in substrate categorized as cobble with sand or silt with plant cover of *Ulva* sp. Young-of-the-year crabs generally were abundant when *Ulva* sp. or *Enteromorpha* sp. were present in any type of substrate. This study indicates the importance of algal habitat to *Cancer magister*.

There are no further reports on the intertidal algal habitat in Padilla Bay. Based on similar studies elsewhere, the presence of extensive macroalgal mats may be due to nutrient inputs in the southern part of Padilla Bay. Nutrient enrichment has increased growth of *Ulva* sp. and *Enteromorpha* sp. in other bays (Bach and Josselyn 1978; Valiela et al. 1992). Such mats have caused decreases in seagrasses (Harlin and Thorne-Miller 1981; Cambridge et al. 1986; Den Hartog 1994) and in benthic infauna (Perkins and Abbott 1972; Hull 1987; Everett 1991). In a report of an investigation into potential pollution in Padilla Bay, Neale (1952) reported that "a heavy growth of seaweed (lettuce)" covered oyster beds in Padilla Bay. These oyster beds were located in the same general area as the macroalgal mats mapped in the current study: west of Bay View and south of the Bay View Channel.

Intertidal Unconsolidated Bottom: Sand

The intertidal sand habitat in Padilla Bay is located primarily between the dikes (and ridges) that border Padilla Bay and the eelgrass-covered intertidal flats that extend throughout most of Padilla Bay (Figure 1). There are also some patches of intertidal sand intermixed among the eelgrass meadows. Such patches are particularly common along the channel edges and near the "headwaters" of the tidal channels (Bulthuis 1991). The total area covered by intertidal sand habitat is an estimated 1,350 ha.

Particle-size distribution of sediments has been measured in one study on the soils of Padilla Bay (Turner 1980) and as an ancillary measurement in several other studies (Scott 1973; Smith and Webber 1978; Bulthuis 1991; Bulthuis and Shaw 1992). These studies indicate a mixed silt and sand, with most sites characterized as predominantly sand mixed with some silt. In samples taken near the southern end of Padilla Bay, the sediments are predominantly silt and clay (>50 percent of the particles <62.5 μm). However, the limited number of total samples throughout the bay preclude accurate mapping of the habitats based on particle-size distribution, and the boundary between the intertidal sand and intertidal mud habitats can only be estimated roughly. Thus, the 1,350 ha of intertidal sands is an estimate based on an "educated guess" that about half of the "bare" intertidal flats in the south part of Padilla Bay are muds and half are sands. The sands are generally mixed fines on the tidal flats, but coarser in some of the sand hummocks near the channel edges.

Within Padilla Bay, there have been few studies of the animal communities in and on the sandy intertidal habitats. Smith and Webber (1978) sampled along one transect in Padilla Bay that included some samples in the sandy intertidal, although most of the transect was in areas covered by at least some eelgrass. Smith and Webber reported high numbers of the clam *Mya arenaria* at the transect location where no eelgrass was reported. (This site was at a tidal height of +6 ft (relative to Port Townsend tidal datum)). Other bivalve species reported by Smith and Webber were found mainly in the eelgrass areas of the transect and were not reported present in the sandy intertidal portion of the transect. The polychaetes *Capitella capitata*, *Polydora kempi-japonica*, and *Abarenicola* sp. were abundant at the sandy intertidal site.

Antrim (1985) measured trace metals in sediments and the gastopod *Batillaria attramentaria* from Padilla Bay. Most of the sample sites were in sandy intertidal sediments. Concentrations of cadmium, copper, lead, and mercury were all relatively low in both sediments and *B. attramentaria*.

Japanese oysters (*Crassostrea gigas*) were cultivated on the sand flats in Padilla Bay in the early to mid 1900s. Orlob, Neale, and Lindsay (1950) and Neale (1952) reported on the condition of the oysters and the possibility that sulfite waste liquor was causing mortalities. Pacific oyster was once very abundant on the sandy intertidal flats of Padilla Bay; but without cultivation and reseeding, oysters are no longer common on the sandy flats where they were once cultured (Bulthuis, personal observation).

Foraminifera assemblages on the sandy intertidal flats in northwestern Padilla Bay were reported by Scott (1973, 1974). Sediment grain size and depth of exposure are reported as the most important factors in determining the assemblages. Assemblages in both Padilla Bay and Samish Bay have large numbers of *Trochammina pacifica*. Other common foraminifera in Padilla Bay include *Elphidium hannai*, *Bucrella frigida*, *Eggerella advena*, and *Miliammina fusca*.

Harbor seals (*Phoca vitulina*) haulout on the sand flats in Padilla Bay during low tide. Harbor seals feed in the channels and over the eelgrass beds and, thus, are an important component of the fauna of these other habitats. However, most of the study of seals in Padilla Bay has been during haulout on intertidal sandflats. Pupping of seals was reported from Padilla Bay in 1928 (Scheffer and Slipp 1944), and the bay has probably been used by harbor seals for haulout and pupping since prior to European settlement of the area. Pupping in Padilla Bay also has been reported by Newby (1973), Everitt, Fiscus, and DeLong (1980), and an unpublished report.[1] Another

[1] McLanahan, E. C., Scholz, A. T., O'Laughlin, K., and Cassidy, P. "Radiotelemetry investigations of harbor seal (*Phoca vitulina*) summer haulout activity at the Padilla Bay National Estuarine Sanctuary," unpublished report.

unpublished report tracked seals in Padilla Bay with radiotelemetry.[1] They concluded that Padilla Bay appears to be an important summer haulout used intensively by pregnant and nursing females and their pups. Their studies also indicated a high degree of fidelity to the same haulout areas by seals of both sexes and all ages.

Various counts and estimates have been made of the seal populations in Washington State, Puget Sound, Padilla Bay, and vicinity. Different methods were used in each study, so that comparisons between studies are difficult, but the data indicate that around 100 to 200 harbor seals are in Padilla Bay during the summer using the sand flats as a low-tide haulout site (Table 19). Both Everitt, Fiscus, and DeLong (1980) and an unpublished report[1] concluded that Padilla Bay is important as a haulout area for harbor seals, in part, because of the lack of boat activity near the haulout sites.

Table 19
Counts and Estimates of Harbor Seal, *Phoca vitulina*, Population in Padilla Bay

Counts and Estimates	Date	Location	Source
100	1971-72	Padilla Bay	Newby 1973
165	11 Sep 77	East of Rosario Strait[a]	Calambokidis et al. 1979
255	14, 18 Aug 78	East of Rosario Strait[a]	Calambokidis et al. 1979
0	31 Jan 79	Padilla Bay	Everitt, Fiscus, and DeLong 1980
51	19 Mar 79	Padilla Bay	Everitt, Fiscus, and DeLong 1980
26	17 Apr 79	Padilla Bay	Everitt, Fiscus, and DeLong 1980
25	26 Apr 79	Padilla Bay	Everitt, Fiscus, and DeLong 1980
21	23 May 79	Padilla Bay	Everitt, Fiscus, and DeLong 1980
95	21 Jun 79	Padilla Bay	Everitt, Fiscus, and DeLong 1980
76	6 Aug 79	Padilla Bay	Everitt, Fiscus, and DeLong 1980
155	1983	Padilla Bay	Unpublished report[b]
208	1984	Padilla Bay	Unpublished report[b]

[a] Includes Bellinham, Padilla, Samish, and Skagit bays.
[b] McLanahan, E. C., Scholz, A. T., O'Laughlin, K., and Cassidy, P. *"Radiotelemetry investigations of harbor seal (Phoca vitulina) summer haulout activity at the Padilla Bay National Estuarine Sanctuary,"* Unpublished report.

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1 McLanahan, E. C., Scholz, A. T., O'Laughlin, K., and Cassidy, P. "Status of the harbor seal (*Phoca vitulina*) population in northern Puget Sound and San Juan Islands: 1983-1984," unpublished report.

Mayer and Elkins (1990) measured herbicides in the sandy intertidal sediments near the mouth of sloughs draining agricultural fields. They did not detect most of the herbicides being used by the farmers during the study, but did detect very low concentrations of Dicamba and 2,4-D. They concluded that no ecologically significant levels of the 14 herbicides that they studied were present in the Padilla Bay sediments.

Intertidal Unconsolidated Bottom: Mud

Padilla Bay has extensive intertidal habitats covering about 5,000 ha, 85 percent of the bay. These flats are referred to as mud flats, tidal flats, or sand flats in various studies of Padilla Bay. The terms are often used interchangeably or often called mud flats in contrast to flats with well-sorted or coarser grain sands or sands with less silt and clay than Padilla Bay (e.g., Birch Bay). This imprecise use of terms may be attributable to the mixture of sands, silts, and clays that make up the intertidal flats in Padilla Bay and the lack of data on particle-size composition of the flats. In this report, sand habitat refers to surface sediments in which "the unconsolidated particles smaller than stones are predominantly sand" (Cowardin et al. 1979). Because of the mixture of sand, silt, and clay in Padilla Bay, intertidal habitats in which the surface sediments are greater than 50-percent sand by weight are classified intertidal sand habitat, and those flats with greater than 50-percent silt plus clay are classified intertidal mud habitat. While there have not been any comprehensive surveys of the sediment size distribution in Padilla Bay (although Turner (1980) did conduct a general—if not comprehensive—survey of sediments throughout Padilla Bay), the sediment size distribution has been measured as an adjunct measurement in many studies. A review of these various studies indicates that most of the intertidal flats in Padilla Bay are sand flats. Sites at which silt plus clay was the predominate grain size were two scattered sites in the central bay and sites in the southernmost part of Padilla Bay. The delineation between the intertidal sand habitat and the intertidal mud habitat in Padilla Bay is not known. However, a line drawn between the sites where mud was predominate and the sites where sand was predominate can be used to estimate the location of intertidal mud habitat and yields an estimate of 350 ha in Padilla Bay (Table 4).

The intertidal mud habitat has received very little attention or study in Padilla Bay. Only six studies (out of about 140 studies listed by Bulthuis 1993a) include a sampling site in the muddy intertidal. Three of those studies deal with sediment toxicity or contamination, two report sediment grain size, and one (Ruckelshaus, Wissmer, and Simenstad 1993) reports on seston characteristics and mussel growth in the water column above a muddy intertidal habitat.

Turner (1980) reported muddy sediments (silt plus clay >50 percent by weight) in the upper 30 cm at 5 sites in the southern part of Padilla Bay out of 35 sites sampled throughout the bay. In addition to particle size and organic

matter, Turner measured the phosphorus, potassium, boron, calcium, magnesium, and cation exchange capacity of the sediments (Table 20). The muddy intertidal sites had somewhat higher concentrations of organic matter, calcium, magnesium, and a higher cation exchange capacity than the sandy sediments in the rest of Padilla Bay in Turner's study. Bulthuis (1991) reported a low cover (4 percent) of macroalgae (*Ulva* sp. and *Enteromorpha* sp.) on a muddy intertidal site.

Table 20
Grain-Size Distribution and Composition of Surface Sediments in Intertidal Mud Habitats in Padilla Bay as Measured in Five Studies

	Percent			Organic		$\mu g\ g^{-1}$			
Site ID	Sand	Silt	Clay	Percent Volatile	$gC\ kg^{-1}$	P	K	B	Source
T 4				2.6		3.0	500	9.6	Turner 1980
T 5				2.7		5.6	600	10.5	Turner 1980
T 35				2.1		3.7	400	7.4	Turner 1980
T 36				2.3		2.8	410	7.4	Turner 1980
T 39				3.8		1.9	650	8.4	Turner 1980
A 4	16	84		6.9					Antrim 1985
B 13	26	74		2.8					Bulthuis 1991
WA	2	92	4	12					Wiggins 1992
WB 2	13	78	8	5.8					Wiggins 1992
WC	8	86	6	19					Wiggins 1992
SH 93	31	54	15		7.1				Bulthuis and Shaw 1992
SH 100	8	70	22		15				Bulthuis and Shaw 1992
SH 39	16	74	10		11				Bulthuis and Shaw 1992
SH 40	8	62	30		19				Bulthuis and Shaw 1992
SH 130	9	67	24		20				Bulthuis and Shaw 1992
SH 131	6	67	27		17				Bulthuis and Shaw 1992
SH 132	9	69	22		16				Bulthuis and Shaw 1992

Note: Locations of sample sites are shown in Figure 5.

The muddy intertidal sediments may become contaminated with anthropogenic pollutants. Several of the metals and numerous organic compounds tend to be adsorbed onto clay and silt particles that make up the mud sediments. In Padilla Bay, most of the muddy intertidal sediments are located in the southern part of the bay where sloughs drain agricultural areas and may bring pesticides and other pollutants into the bay. Another potential source of

toxicants to the muddy intertidal is the sea surface microlayer. Gardiner (1992) measured deposition of sea surface microlayer during ebb tide in Padilla Bay, Commencement Bay, and Discovery Bay. Surface deposits in Padilla Bay had higher toxicities than the bulkwater as measured by the echinoderm sperm cell test. In the muddy intertidal, such deposits may become incorporated into the sediments, and subsequent ebbing tides may contribute more contaminants. Gardiner (1992) found that surface deposits in Padilla Bay had an intermediate toxicity between Discovery Bay (near Gardiner) and Commencement Bay (Tacoma).

Three studies considered sediment toxicity or metal contamination in muddy intertidal sites. Antrim (1985) reported relatively low concentrations of cadmium, copper, lead, and mercury in the sediments. The mud snail *Batillaria attramentaria* accumulated high levels of cadmium and copper in soft tissues, but this appeared to be unrelated to any sources of contamination. Bulthuis and Shaw (1992) reported significant sediment toxicity at three out of four muddy intertidal sites using the *Rhepoxynius abronius* sediment toxicity test. The percent mortality was higher than would be expected on the basis of percent fines (DeWitt, Ditsworth, and Swartz 1988), but consistent with the low-level toxicity found in sediments throughout Padilla Bay. Bulthuis and Shaw (1992) reported high toxicity at three additional sites near a landfill that was more extensively studied by Wiggins (1992). He found high toxicity in the upper 2 cm of sediments near the landfill, but no difference in the toxicity of the upper 2 mm of sediment compared with a control site. These toxicity levels were associated with an abandoned landfill and do not indicate high toxicity throughout the muddy intertidal in Padilla Bay.

The only samples of organisms in the muddy intertidal were by Antrim (1985) and Wiggins (1992) for epibenthic species and by Ruckelshaus, Wissmar, and Simenstad (1993) for phytoplanktonic and epibenthic species. Antrim measured the concentration of metals in molluscs that were collected from the mud surface. Organisms that were collected included *Crassostrea gigas*, *Macoma* spp., and *Mytilus edulis*. Wiggins collected epibenthic harpacticoid copepods from the muddy intertidal sediments near the abandoned Whitmarsh landfill. Mean density of harpacticoid copepods at three sites varied from 400 to 800 copepods m^{-2}. More than 95 percent of the copepods were in the genera *Harpacticus* or *Tisbe* with the remaining individuals in the genera *Dactylopodia*, *Zaus*, and *Scutellidium* and the families Ectinosomatidae and Lauphontidae. Ruckelshaus, Wissmar, and Simenstad (1993) collected planktonic and epibenthic samples from a muddy site in Indian Slough in August. The most abundant species were *Chaetocerus radicans*, *C. seriacanthus*, *Tetraselmis* sp. (a freshwater species presumably transported passively into the estuary), *Melosira moniliformis*, *Melosira* sp., *Navicula distans*, *N. seriata*, and a third *Navicula* sp.

Intertidal Unconsolidated Bottom: Cobble-Gravel

The intertidal gravel habitat in Padilla Bay occurs in gravel bars offshore from failed dikes and from eroding bluffs along Bay View Ridge and Samish Island. The area covered by these gravel bars is small and has not been determined quantitatively, but represents much less than 1 percent of the intertidal area in Padilla Bay. Gravel bars offshore of Bay View Ridge have been studied by Smith and Webber (1978) and Bulthuis (1991). In addition, Dinnel et al. (1986), McMillan (1991), and McMillan et al. (unpublished manuscript) studied Dungeness crab recruitment and survival in a variety of habitats in Padilla Bay including some with gravel. Other authors have referred to gravel areas or patches, but their grain-size analyses indicate that these habitats would be considered intertidal sand in the Coastal Habitat Classification Scheme.

Bulthuis (1991) found little vegetative cover on a 1-ha site on a gravel patch immediately offshore of a failed dike and seawall below Bay View Ridge. Total seagrass and macroalgal biomass was less than 1 g dry wt m^{-2}. The sediments were poorly sorted with sand and mud intermixed with gravel. Smith and Webber (1978) refer to pebble-dominated areas in their transect in Padilla Bay, and particle-size analysis at one tidal height during one season indicated a poorly sorted gravel substrate. However, the sampling design used by Smith and Webber was oriented around sediment height relative to tidal datum. Therefore, the data on plant and animal communities cannot be separated between gravel and sand areas. Since most of the sample sites for which particle analysis was measured were sandy, the information from the report by Smith and Webber (1978) is discussed in the intertidal sand habitat in the present report.

Dinnel et al. (1986) measured density of *Cancer magister* (Dungeness crabs) in seven different intertidal habitats, with and without macrophyte cover. The gravel/sand/silt habitat had almost no crabs, whereas the same sediment type with an algal cover (*Ulva* sp.) was an important habitat for young-of-the-year *C. magister*.

In summary, the intertidal gravel habitat is sparsely represented in Padilla Bay, being scattered in bars and beaches along the perimeter of the bay, with very little known about the animals in this habitat in Padilla Bay.

Intertidal Rock Bottom

Intertidal rock bottom is sparsely distributed in Padilla Bay. The shorelines of Hat Island, Saddlebag Island, and Dot Island have intertidal bedrock. Along the shoreline below Bay View Ridge and Samish islands, as well as in pockets around Hat, Saddlebag, and Dot islands, intertidal rock rubble is scattered on sands. There are no estimates of the area of these habitats, although the combined perimeter of Hat, Saddlebag, and Dot islands mainly consist of

intertidal rock bottom. Rocks are only sparsely scattered along the Samish Island and Bay View Ridge shoreline (Kueler 1979; Bulthuis unpublished data).

The only report on biota on intertidal rocks in Padilla Bay is that by Sylvester and Clogston (1958).[1] One intertidal site that they surveyed was located on the southwest coast of Hat Island. Rocks on the upper beach had *Littorina sitka*, *Acmea digitalis*, and a sparse population of *Balanus glandula*. Rocks in the middle and lower beach were covered with a rich growth of algae including *Laminaria* sp., *Ulva* sp., *Costaria costata*, and *Gigartina* sp. Rocks in the lower intertidal had *Balanus cariosus*, *Mytilus edulis*, *Thais lamellosa*, the turban snail, *Calliostoma costatum*, *Acmea pelta*, and the limpet, *Diodora aspera*. Other common species included *Mopalia muscosa*, the green sea urchin, *Strongylocentrotus droebachiensis*, the seastar, *Pisaster ochraceous*, *Henrecia leviuscula*, and *Leptasterias hexactis*. Common species that Dethier (1990) listed for the estuarine intertidal bedrock included many of those reported by Sylvester and Clogston (1958).[1] In a second intertidal survey site beneath Bay View Ridge, Sylvester and Clogston reported tufts of *Ulva*, *Balanus glandula*, *Mytilus edulis*, and *Acmea digitalis* on the boulders.

In summary, little is known about the intertidal rock in Padilla Bay, nor does it cover very extensive areas. In her review and classification of marine and estuarine habitats in Washington State, Dethier (1990) stated that few complete surveys have been conducted on estuarine intertidal bedrock throughout Washington State.

Intertidal Marsh

Intertidal marsh area was much more extensive in the Padilla Bay region until diking and drainage of the marshes during the last 100 years (Thom and Hallum 1990). The remaining intertidal marshes are mainly narrow bands located seaward of the dikes, lining the sloughs seaward of the tidal gates, and fringing the sand islands formed from dredge spoils along the Swinomish Channel (Figure 1). Bulthuis (1991) estimated the area of these native salt marshes as 62 ha in Padilla Bay (Table 4).

The low intertidal marshes that occur on the perimeter of Padilla Bay are dominated by *Salicornia virginica* and *Distichlis spicata* with *Triglochin maritimum* and *Atriplex patula* also common (Granger and Burg 1986; Bulthuis 1991; Bulthuis and Scott 1993). Granger and Burg (1986) described seven plant communities in a 3.4-ha strip of salt marsh along Bay View ridge—the "Sullivan-Minor marsh." This marsh had been diked and drained in the late 1800s or early 1900s, but had reverted back to salt marsh after the failure of

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1 Sylvester, R. O., and Clogston, F. L. (1958). "A study of the preoperational marine environment in the vicinity of the Texas Company Refinery Puget Sound Works, Anacortes, Washington," Unpublished report to Texas Company.

the seawall protecting the diked land. *Salicornia virginica*, *D. spicata*, and *A. patula* were the most widespread species in the marsh with some 15 other species also noted. Freshwater species such as *Typha latifolia*, *Phalaris arundinacea*, and *Carex lyngbyei* dominate in the corners of the marsh and near the base of the cliff where fresh water from upland drainage flows into the marsh. *Distichlis spicata* occurs in all of the salt marsh associations in this marsh and dominates in the transitional areas between high and low marsh. The *S. virginica* community is found at low elevations in the marsh and around salt pans.

The vertical range for native salt marsh species in Padilla Bay as measured by Beale (1990) and Bulthuis and Scott (1993) is from about 1.2 to 1.9 m above mean sea level. *Distichlis spicata* ranges from about 1.2 to 1.7 m in the Sullivan-Minor marsh (Beale 1990) and from 1.5 to 1.9 m near Dike Island in southern Padilla Bay (Bulthuis and Scott 1993).

The Sullivan-Minor salt marsh apparently developed at its present location about 4,000 years ago; since then, the area has alternated between salt marsh and tidal flat (Beale 1990). Radiocarbon dating of peat samples indicates a relative sea level rise of 2 to 3 m between 5,000 and 3,000 years ago and about a 1-m rise between 3,000 and 1,000 years ago. In the last 1,000 years, sea level rise has been less than 1 m (Beale 1990). Thom (1992) measured the rate of accretion during the last 40 years in this same marsh and estimated a rate of 4.5 mm $year^{-1}$, about three times the annual relative rate of sea level rise.

In addition to the relict native salt marshes in Padilla Bay, the exotic eastern United States species, *Spartina alterniflora*, is growing and becoming established in the bay. *Spartina alterniflora* was apparently introduced to Padilla Bay in the 1940s to stabilize the sediment (Parker and Aberle 1979;[1] Frenkel and Kunze 1984; Wiggins and Binney 1987). *Spartina alterniflora* has spread vegetatively and now covers about 4.8 ha (Riggs 1992). Riggs (1992) estimated lateral growth of clumps of *S. alterniflora* from 1.1 to 1.7 m $year^{-1}$. *Spartina alterniflora* is now perceived as a threat to estuaries in Washington State (Mumford et al. 1991) and has been declared a noxious plant in parts of the State (Washington State 1989; Ebasco Environmental 1992). Herbicides have been tested for their effectiveness on *S. alterniflora* in Padilla Bay, but none of the treatments were effective in killing most of the cordgrass within the treatment plots (Parker and Aberle 1979;[1] Bulthuis and Scott 1993).

Standing stock of native salt marsh and *Spartina alterniflora* in the few measurements that have been taken are similar to values reported elsewhere. Thom (1992) reported about 550 g dry wt m^{-2} in July/August for a site in the Sullivan-Minor marsh of which about 150 g was *Distichlis spicata* and the

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1 Parker, R. C., and Aberle, B. (1979). "A situation report on the *Spartina* infestation in northwest Washington," Unpublished report by Washington State Department of Game.

remainder *Salicornia virginica*. At one site on Dike Island in southern Padilla Bay, the range of mean standing stock during July and August 1992 and 1993 was 70 to 160 g m^{-2} for *Atriplex patula*, 22 to 94 g m^{-2} for *Distichlis spicata*, 90 to 580 g m^{-2} for *Salicornia virginica*, and 160 to 730 g m^{-2} for *Spartina alterniflora* (Bulthuis and Scott 1993).

Subtidal Rock Bottom

Subtidal rock habitat occurs in Padilla Bay around Hat Island, Saddlebag Island, and Dot Island (Bulthuis, unpublished data). However, there are no written reports or surveys of such habitats in Padilla Bay. Sylvester and Clogston (1958)[1] referred to beds of the kelp, *Nereocystis luetkeana*, on the subtidal rocks off Hat Island. Dethier (1990) lists *Nereocystis luetkeana*, *Agarum* spp., and *Metriduim* spp. as diagnostic species in estuarine shallow subtidal rock habitats and would be expected to occur also in Padilla Bay.

Subtidal Unconsolidated Bottom: Sand

Most of the 700 ha of subtidal unvegetated habitat in Padilla Bay is made up of sandy-bottom channels and a deep area off Hat Island (Figure 1). The Swinomish Channel is dredged regularly with a minimum reported depth of 7.6 ft below mean lower spring tides. The remaining channels have depths ranging from just subtidal to about 30 ft below MLLW. The channels in Padilla Bay, Swinomish Channel, and Guemes Channel converge east of Hat Island over a hole with depths down to 270 ft. The bottom sediments in the channels are generally unstable with shifting sand waves. The sediments in the deep area east of Hat Island are mixed sand, shell, and mud and, based on the few samples that have been taken in this area, are classified subtidal sand in this report, although further sampling may indicate muddy sediments in the deepest portions (Sylvester and Clogston 1958;[1] Smith 1979; Barreca 1982).

The fauna of the subtidal area was sampled by dredge by Sylvester and Clogston (1958)[1] at two sites at a depth of 30 ft. Characteristic fauna were small clams, serpent stars, and polycheates worms. Common biota in the samples included the polycheates *Sternaspis fossor*, *Lumbrineries latreilli*, *Nephthys ciliata*, and *Armandia brevis* and the serpent star *Amphioda urtica*. Other animals in the dredge samples at 30 ft were the clams *Macoma nasuta*, *Protothaca staminea*, *Yoldia* sp., *Nucula* sp. Gammarid amphipods, and *Pinnida schmith*. One of Sylvester and Clogston's sites was between Saddlebag and Huckleberry islands at a depth of 265 ft where they reported finding many bryozoans (*Membranipora* sp.) and hydroids (*Abietinaria*

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[1] Sylvester, R. O., and Clogston, F. L. (1958). "A study of the preoperational marine environment in the vicinity of the Texas Company Refinery Puget Sound Works, Anacortes, Washington," Unpublished report to Texas Company.

variabilis, *Abictinaria* sp., *Thuiaria argeutea*, and *Halecium* sp.) on shells; numerous crustacea including isopods (*Rocinela angrestata*), shrimps (*Crago alaskensis*), and crabs (*Oregonia gracilis*, *Hyas* sp., and *Cancer oregonensis*) and many molluscs (*Ischonchiton mertensii*, I. *cooperii*, *Trichotropus* sp., *Calyptaea fastigiata*, *Yoldia* sp., *Cardita* sp., *Acila* sp., and *Humilarea* sp.).

Smith (1979) sampled the fauna at 8, 23, and 43 ft below MLLW. At all three depths, high counts of bivalves, polychaetes, isopods, and amphipods were reported although genera and species are not reported specifically for the Padilla Bay samples. Goodwin (1973) reported no commercial-size butter clams (*Saxidomus gigonteus*) nor native littleneck clams (*Protothaca staminea*) at five subtidal sites off the northern eelgrass beds in Padilla Bay.

Barreca (1982) reported infauna from three sites between March Point and Hat Island at a depth of -9 m (Table 21). Numerically abundant taxa and

Table 21
Taxa That Were Most Abundant and Had Highest Biomass in Samples Taken in February and July From Three Sites at a Depth of -9 m Between Hat Island and March Point by Barreca (1982)

Nematoda
Polychaeta
Prionospio steenstrupi
Lumbrineris californiensis
L. luti
L. bicirrata
Glycinde picata
Nephtys cornuta franciscana
Sternapsis fossor
Owenia fusiformis
Armandia brevis
Scoloplos pugettensis
Axiothella rubroncincta
Pista brevibranchiata
Laonice cirrata
Mollusca: Bivalvia
Psephidia lordi
Axinopsida sericata
Mysella turnida
Tellina modesta
Nuculana sp.
Protothaca spp.
Nucula tenuis
Acila castrensis
Crustaceae
Euphilomedes carcharodonta
Paraphoxus epistomus
Eudorella pacifica
Echinodermata
Amphiodia urtica

those taxa comprising the highest biomass included the bivalve *Psephidia lordi*, the crustacean *Euphilomedes carrharodonta*, the echinoderm *Amphiodia urtica*, and the polychaete *Pista brevibranchiata*. The species composition and diversity at the three sites appeared to be associated with sediment grain size rather than concentrations of petroleum or densities of petroleum-degrading bacteria.

The sandy subtidal habitat including the channels is particularly important for the Dungeness crab in Padilla Bay because of the proximity of the intertidal and subtidal eelgrass beds. In contrast to younger (first-year) crabs that were found in greater numbers in the intertidal eelgrass, the older crabs favored the deeper channels (Dinnel et al. 1986). In the channels nearest the intertidal eelgrass beds, the mean density of Dungeness crabs was up to 1,600 crabs per hectare with averages of 500 to 900 in many of the channels. Seasonally, more crabs were caught during summer and autumn than during winter. The channels are used heavily by commercial and recreational fishermen for catching Dungeness crabs with baited crab pots. Size frequency histograms indicate that the crabs in the channels are grouped in size just below the minimum allowable size that can be taken ($\sim$150 mm). In addition to Dungeness crabs, rock crab and red rock crab are found in high numbers in the subtidal sandy habitat in Padilla Bay in densities up to 80 and 50 crabs per hectare, respectively (Dinnel et al. 1986). Thus, the sandy subtidal channels in Padilla Bay are important habitat for Dungeness, rock, and red rock crabs.

Fish that were abundant (> 100 per hectare) and caught specifically above the sandy subtidal bottoms of the channels included English sole, staghorn sculpin, buffalo sculpin, padded sculpin, tadpole sculpin, snake prickleback, shiner perch, and tubesnout (Dinnel et al. 1990, Figure 4). All of these fish were seasonally abundant with the high catches (> 100 fish per hectare) reported during June, July, and August, but not for any other months of the year. The English sole and buffalo sculpin were found mainly in the channel habitat, whereas the rest of the fish were caught in even higher numbers in the subtidal or intertidal eelgrass habitats. Thus, only the English sole and buffalo sculpin showed a preference for the channel habitat. For many fish, the channel habitat may provide an important pathway for access to the intertidal eelgrass habitat as well as a "refuge" during times of intertidal exposure.

Diving ducks and sea ducks are common in Padilla Bay (Jeffrey 1976; Table 22) and move from one habitat to another. At least part of their time feeding in Padilla Bay is spent in the channels over the sandy subtidal habitat as well as over the eelgrass habitats. Besides the counts of number of diving and sea ducks reported by Jeffrey (1976), there are no studies of the habitat use or preferences of these birds in Padilla Bay.

Subtidal sediments can be "sinks" for organic and inorganic pollutants. Barrick, Hedges, and Peterson (1980), Barrick and Hedges (1981), Barrick and Prahl (1987), and Carpentar, Peterson, and Bennett (1985) sampled sediments from throughout Puget Sound including a couple of sites in Padilla Bay and measured hydrocarbons and hydrocarbon accumulation in the sediments.

Table 22
Annual Estimates of Number of Diving and Sea Ducks in Two Sample Plots in Padilla Bay From 1965 to 1974 and an Estimate of Total in Padilla Bay

Year	Canvasback	Scaup	Goldeneye	Bufflehead	Old Squaw	Scoter
1965	0	131	25	43	18	87
1966	0	201	27	45	0	474
1967	1	57	3	131	0	119
1968	15	133	8	66	0	195
1969	10	571	11	427	3	80
1970	0	9	13	178	0	220
1971	15	33	9	377	4	273
1972	0	426	24	142	0	156
1973	85	475	10	411	0	69
1974	0	390	73	274	0	0
Average	12.6	242.6	20.3	209.4	2.5	167.3
Padilla Bay Total	118	2,280	191	1,968	23	1,572

Note: From Jeffrey 1976.

Padilla Bay had one of the highest concentrations of combustion-derived polycyclic aromatic hydrocarbons (200 mg/g) and had the highest reported surface accumulation rates (600 ng cm^2/year) of combustion-derived polycyclic aromatic hydrocarbons. The reason for this high rate of accumulation is not clear, but Barrick and Prahl (1987) imply that it may be due to the close proximity of the oil refineries on March Point.

3 Summary

Padilla Bay is a shallow, protected, polyhaline estuary in North Puget Sound, Washington. The most extensive habitat in the bay is the intertidal eelgrass habitat (Intertidal Aquatic Bed: Rooted Vascular) that covers about 3,000 ha, about one-half of the surface area of the bay. Eelgrass habitat is highly productive with epiphytes of eelgrass responsible for about half of the primary productivity. A wide range of marine animals live in the eelgrass habitat or utilize it for certain life cycle stages or times of the year. Primary productivity flows through both the detrital food web and a grazer food web to secondary producers. Harpacticoid copepods, nematods, polychaetes, amphipods, and isopods are abundant and important in the food web to higher organisms. Dungeness crab use the eelgrass habitat during early stages of their life cycle. Juvenile chum salmon, surf smelt, Pacific herring, sculpins, and other fish feed in the intertidal eelgrass. Brant, widgeon, pintail, mallard, teal, and other waterfowl are seasonally abundant in Padilla Bay, utilizing the eelgrass habitat. Other intertidal habitats that cover extensive areas in Padilla Bay include the sand habitat (Intertidal Unconsolidated Bottom: Sand) covering about 1,350 ha and mud habitat (Intertidal Unconsolidated Bottom: Mud) covering about 350 ha. Subtidal channels that distribute and drain tidal water to and from the intertidal flats are important refuge areas for animals that use the eelgrass habitat during high tide as well as the predominate habitat for some species (e.g., English sole and buffalo sculpin) and for certain life stages (e.g., adult Dungeness, red and red rock crabs). Many of the animals higher in the food chain either move freely among habitats or utilize different habitats in the bay during different life stages. The mozaic of habitats in Padilla Bay support an abundant and diverse estuarine fauna.

References

Antrim, L. D. (1985). "Trace metals in the ecosystem of Padilla Bay, Washington," M.S. thesis, Western Washington University, Bellingham, WA.

Bach, S. D., and Josselyn, M. N. (1978). "Mass blooms of the alga *Cladophora* in Bermuda," *Mar. Pollut. Bull.* 9, 34-37.

Baldwin, J. R., and Lovvorn, J. R. (1992). "Populations, diet, food availability and food requirements of dabbling ducks in Boundary Bay." *Abundance, distribution and conservation of birds in the vicinity of Boundary Bay, British Columbia.* Chapter 3, R. W. Butler, ed., Canadian Wildlife Service, Canadian Wildlife Service Technical Report Series 155, 42-69.

Barreca, J. L. (1982). "Subtidal benthic communities and densities of petroleum-degrading bacteria in Padilla Bay, Washington," M.S. thesis, Western Washington University, Bellingham, WA.

Barrick, R. C., and Hedges, J. I. (1981). "Hydrocarbon geochemistry of the Puget Sound region - II. Sedimentary diterpenoid, steroid and triterpenoid hydrocarbons," *Geochim. Cosmochim. Acta* 45, 381-392.

Barrick, R. C., Hedges, J. I., and Peterson, M. L. (1980). "Hydrocarbon geochemistry of the Puget Sound region - I. Sedimentary acyclic hydrocarbons," *Geochim. Cosmochim. Acta* 44, 1349-1362.

Barrick, R. C., and Prahl, F. G. (1987). "Hydrocarbon geochemistry of the Puget Sound region - III. Polycyclic aromatic hydrocarbons in sediments," *Estuarine Coastal Mar. Sci.* 25, 175-191.

Beale, H. (1990). "Relative rise in sea-level during the late Holocene at six salt marshes in the Puget Basin, Washington," M.S. thesis, Western Washington University, Bellingham, WA.

Bulthuis, D. A. (1991). "Distribution of habitats and summer standing crop of seagrasses and macroalgae in Padilla Bay, Washington, 1989," Padilla Bay National Estuarine Research Reserve Technical Report No. 2, Washington State Deptartment of Ecology, Mount Vernon, WA.

Bulthuis, D. A. (1993a). "Padilla Bay Bibliography, 1993," Padilla Bay National Estuarine Research Reserve Technical Report No. 6, Washington State Department of Ecology, Mount Vernon, WA.

__________. (1993b). "Review of water quality data in the Padilla Bay/Bay View watershed," Padilla Bay National Estuarine Research Reserve Technical Report No. 10, Washington State Deptartment of Ecology, Mount Vernon, WA.

Bulthuis, D. A., and Scott, B. A. (1993). "Effects of application of glyphosate on cordgrass, *Spartina alterniflora*, and adjacent native salt marsh vegetation in Padilla Bay, Washington," Padilla Bay National Estuarine Research Reserve Technical Report No. 7, Washington State Department of Ecology, Mount Vernon, WA.

Bulthuis, D. A., and Shaw, T. (1992). "Acute toxicity of intertidal sediments from Padilla Bay, Washington, to the amphipod, *Rhepoxynius abronius*," Padilla Bay National Estuarine Research Reserve Technical Report No. 4, Washington State Department of Ecology, Mount Vernon, WA.

__________. (1993). "Effects of application of glyphosate on the eelgrasses *Zostera marina* and *Zostera japonica* in Padilla Bay, Washington," Padilla Bay National Estuarine Research Reserve Technical Report No. 8, Washington State Department of Ecology, Mount Vernon, WA.

Caine, E. A. (1991). "Caprellid amphipods: Fast food for the reproductively active," *J. Exp. Mar. Biol. Ecol.* 148, 27-33.

Calambokidis, J. A., Everitt, R. D., Cobbage, J. C., and Carter, S. D. (1979). "Harbor seal census for the inland waters of Washington 1977-1978," *Murrelet* 60, 110-112.

Cambridge, M. L., Chiffings, A. W., Brittan, C., Moore, L., and McComb, A. J. (1986). "The loss of seagrass in Cockburn Sound, Western Australia. II. Possible causes of seagrass decline," *Aquat. Bot.* 24, 269-285.

Carpenter, R., Peterson, M. L., and Bennett, J. T. (1985). "210Pb-derived sediment accumulation and mixing rates for the greater Puget Sound region," *Mar. Geol.* 64, 291-312.

Cassidy, P. M., and McKeen, G. L. (1986). *Padilla Bay baseline water quality record.* Padilla Bay National Estuarine Research Reserve Reprint Series No. 2 (Final report to Marine & Estuarine Management Division, NOAA, Grant No. NA85AA-D-CZ046), Shannon Point Marine Center, Western Washington University, Anacortes, WA.

Clark, J. A. (1981). "Comparisons of biomass, morphology, and reproduction in the eelgrass *Zostera japonica* in two substrate types at three elevations in Padilla Bay, Washington," Student Problem Series Report, Huxley College of Environmental Studies, Western Washington University, Bellingham, WA.

Cordell, J. R., and Simenstad, C. A. (1988). "Epibenthic harpacticoid copepods as indicators of wetland fitness." *Proceedings First Annual Meeting Puget Sound Research.* Puget Sound Water Quality Authority, Seattle, WA, 422-431.

Cowardin, L. M., Carter, V., Golet, F. C., and LaRoe, E. T. (1979). *Classification of wetlands and deepwater habitats of the United States.* FWS/OBS-79/31, U.S. Fish and Wildlife Service, Washington, DC.

Den Hartog, C. (1994). "Suffocation of a littoral *Zostera* bed by *Enteromorpha radiata*," *Aquat. Bot.* 47, 21-28.

Dethier, M. N. (1990). *A marine and estuarine habitat classification system for Washington State.* Washington Department of Natural Resources, Natural Heritage Program, Olympia, WA.

DeWitt, T. H., Ditsworth, G. R., and Swartz, R. C. (1988). "Effects of natural sediment features on survival of the phoxocephalid amphipod, *Rhepoxynius abronius*," *Mar. Environ. Res.* 25, 99-124.

Dinnel, P. A., Armstrong, J. A., Lauth, R. R., Larsen, K., Armstrong, D. A., and Sulkin, S. (1990). *Fish predation on Dungeness Crab in Padilla Bay, Washington.* FRI-UW-9001 Padilla Bay National Estuarine Research Reserve Reprint Series No. 14, 1991, University of Washington, Fisheries Research Institute, Seattle, WA.

Dinnel, P. A., Armstrong, D. A., and McMillan, R. O. (1993). "Evidence for multiple recruitment-cohorts of Puget Sound Dungeness crab, *Cancer magister*," *Mar. Biol.* 115, 53-63.

Dinnel, P. A., McMillan, R. O., Armstrong, D. A., Wainwright, T. C., Whiley, A. J., Burge, R., and Bumgarner, R. (1986). "Padilla Bay dungeness crab, Cancer magister, habitat study," Padilla Bay National Estuarine Research Reserve Reprint Series No. 3, 1990 (Final report to NOAA/MEMD, Washington DC, Grant No. NA85-AA-D-CZ046), University of Washington, Fisheries Research Institute, Seattle, WA.

Ebasco Environmental. (1992). "Final Report Element A Spartina: Distribution, biology, and ecology," Submitted to Washington State Department of Ecology.

Everett, R. A. (1991). "Intertidal distribution of infauna in a central California lagoon: The role of seasonal blooms of macroalgae," *J. Exp. Mar. Biol. Ecol.* 150, 223-247.

Everitt, R. D., Fiscus, C. H., and DeLong, R. L. (1980). *Northern Puget Sound marine mammals*. EPA-600/7-80-139, U.S. Environmental Protection Agency, Washington, DC.

Frenkel, R. E., and Kunze, L. M. (1984). "Introduction and spread of three *Spartina* species in the Pacific northwest," Paper presented at the Annual Meeting of the Association of American Geographers, Washington, DC, April 22-25, 1984.

Fresh, K. L. (1979). "Distribution and abundance of fishes occurring in the nearshore surface waters of northern Puget Sound, Washington," M.S. thesis, University of Washington, Seattle.

Gardiner, W. W. (1992). "Sea surface films: Deposition and toxicity in intertidal habitats," M.S. thesis, Western Washington University, Bellingham, WA.

Goodwin, L. C. (1973). "Distribution and abundance of subtidal hard-shell clams in Puget Sound, Washington," Technical Report 14, Washington Department of Fisheries.

Granger, T., and Burg, M. (1986). "Plant communities of a salt marsh in Padilla Bay, Washington," Padilla Bay National Estuarine Research Reserve Reprint Series No. 4, 1990 (Report to Padilla Bay National Estuarine Research Reserve), Washington State Department of Ecology, Shorelands and Coastal Zone Management Program, Wetlands Section, Olympia, WA.

Harlin, M. M., and Thorne-Miller, B. (1981). "Nutrient enrichment of seagrass beds in a Rhode Island coastal lagoon," *Mar. Biol.* 65, 221-229.

Harrison, P. G. (1982a). "Comparative growth of *Zostera japonica* Aschers. and Graebn. and *Z. marina* L. under simulated intertidal and subtidal conditions," *Aquat. Bot.* 14, 373-379.

__________. (1982b). "Spatial and temporal patterns in abundance of two intertidal seagrass, *Zostera americana* Den Hartog and *Zostera marina* L.," *Aquat. Bot.* 12, 305-320.

__________. (1989). "Detrital processing in seagrass systems: A review of factors affecting decay rates, remineralization and detritivory," *Aquat. Bot.* 23, 263-288.

Harrison, P. G., and Bigley, R. E. (1982). "The recent introduction of the seagrass *Zostera japonica* Aschers. and Graebn. to the Pacific Coast of North America," *Can. J. Fish. Aquat. Sci.* 39, 1642-1648.

Hemminga, M. A., and Nieuwenhuize, J. (1991). "Transport, deposition and in situ decay of seagrasses in a tropical mudflat area (Banc D'Arguin, Mauritania)," *Neth. J. Sea Res.* 27, 183-190.

Hull, S. C. (1987). "Macroalgal mats and species abundance: A field experiment," *Estuarine Coastal and Shelf Science* 25, 519-532.

Jeffrey, R. (1976). "A preliminary inventory of the biota of Padilla Bay," Padilla Bay National Estuarine Research Reserve Reprint Series No. 1.

Jeffrey, R., Parker, R. C., and Henry, P. M. (1977). *Wetlands Survey, Northwestern Washington.* Washington Department of Game.

Klug, M. J. (1980). "Detritus-decomposition relationships." *Handbook of seagrass biology: An ecosystem perspective.* R. C. Phillips and C. P. McRoy, ed., Garland STMP Press, New York, 225-245.

Koons, R. R., and Cardwell, R. D. (1981). "Significant areas for certain species of food fish and shellfish in Puget Sound," Technical Report 59, Washington Department Fisheries, Olympia, WA.

Kueler, R. F. (1979). "Coastal zone processes and geomorphology of Skagit County, Washington," M.S. thesis, Western Washington University, Bellingham, WA.

Laushman, R. H. (1993). "Population genetics of hydrophilous angiosperms," *Aquat. Bot.* 44, 147-158.

Mayer, J. R., and Elkins, N. R. (1990). "Potential for agricultural pesticide runoff to a Puget Sound estuary: Padilla Bay, Washington," *Bull. Environ. Contam. Toxicol.* 45, 215-222.

McMillan, R. O. (1991). "Abundance, settlement, growth and habitat use by juvenile Dungeness crab, *Cancer magister*, in inland waters of northern Puget Sound, Washington," M.S. thesis, University of Washington, Seattle.

McRoy, C. P., and Barsdate, R. J. (1970). "Phosphate absorption in eelgrass," *Limnol. Oceanogr.* 15, 6-13.

McRoy, C. P., and Goering, J. J. (1974). "Nutrient transfer between the seagrass *Zostera marina* and its epiphytes," *Nature (London)* 248, 173-174.

McRoy, C. P., and McMillan, C. (1977). "Production ecology and physiology of seagrasses." *Seagrass ecosystems.* C. P. McRoy and C. Helfferich, ed., Marcel Dekker, New York, 53-87.

Miller, B. S., Simenstad, C. A., Moulton, L. L., Fresh, K. L., Funk, F. C., Karp, W. A., and Borton, S. F. (1977). "Puget Sound Baseline Program nearshore fish survey," Baseline Study Program North Puget Sound, Appendix O, Nearshore Fishes final report July 1974 - June 1977, Washington Department of Ecology, Olympia, WA.

Morton, M. D. (1988). "Mapping seagrass meadows using Landsat-5 TM imagery and a microcomputer," M.S. thesis, Western Washington University, Bellingham, WA.

Mumford, T. F., Peyton, P., Sayce, J. R., and Harbell, S. (1991). *Spartina Workshop Record.* Record of workshop held November 14-15, 1990 in Seattle, WA, Washington Sea Grant Program, Seattle, WA.

Neale, A. T. (1952). "Report of an investigation of the condition of oysters on Pioneer Oyster company beds 1, 2 and 3 in Padilla Bay," Washington Pollution Control Commission.

Newby, T. C. (1973). "Changes in the Washington State harbor seal population 1942 - 1972," *Murrelet* 54, 4-6.

Orlob, G. T., Neale, A. T., and Lindsay, C. (1950). "Pulp mill pollution and oyster culture in Padilla and Fidalgo bays, a preliminary survey," Washington Pollution Control Commission.

Orth, R. J., and Moore, K. A. (1986). "Seasonal and year-to-year variations in the growth of *Zostera marina* L. (eelgrass) in the lower Chesapeake Bay," *Aquat. Bot.* 24, 335-341.

__________. (1987). "Quality assurance project plan for the 1987 submerged aquatic vegetation distribution and abundance survey of the Chesapeake and Chincoteague bays," Virginia Institute Marine Sciences, Gloucester Point, VA.

Orth, R. J., Moore, K. A., and Nowak, J. F. (1990). "Monitoring seagrass distribution and abundance patterns: A case study from the Chesapeake Bay." *Federal coastal wetland mapping programs.* S. J. Kiraly, F. A. Cross, and J. D. Buffington, ed., Biological Report 90(18), U.S. Fish and Wildlife Service, Washington, DC, 111-123.

Orth, R. J., and Nowak, J. F. (1990). *Distribution of submerged aquatic vegetation in the Chesapeake Bay and tributaries and Chincoteague Bay - 1989.* Final report submitted to U.S.E.P.A., Chesapeake Bay Program, Annapolis, MD, Virginia Institute of Marine Science, Gloucester Point, VA.

Pantalone, V. (1985). "Opportunistic feeding habits of the Pacific staghorn sculpin (*Leptocottus armatus*) in Padilla Bay, Washington," Student report, University of Washington, Seattle.

Pauley, G. B., Armstrong, D. A., and Heun, T. W. (1986). "Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest)—Dungeness crab," U.S. Army Corps of Engineers, Waterways Experiment Station, Coastal Ecology Group and U.S. Department of the Interior, Fish and Wildlife Service, Research and Development, National Wetlands Research Center.

Pentilla, D. (1984). "Summary of winter herring hydroacoustic/trawl surveys in the Bellingham Bay area December 1983 - January 1984," Washington Department of Fisheries, (Briefing report).

__________. (1985). "Summary of winter herring hydroacoustic/trawl surveys in the Bellingham Bay area December 1984 - January 1985," Washington Department of Fisheries, (Briefing report).

Perkins, E. J., and Abbott, O. J. (1972). "Nutrient enrichment and sand flat fauna," *Mar. Pollut. Bull.* 3, 70-72.

Phillips, R. C. (1972). "Ecological life history of *Zostera marina* L. (eelgrass) in Puget Sound, Washington," Ph.D. diss., University of Washington, Seattle.

Powell, G. V. N., and Schaffner, F. C. (1991). "Water trapping by seagrasses occupying bank habitats in Florida Bay," *Estuarine Coastal Shelf Sci.* 32, 43-60.

Ray, G. C. (1975). "A preliminary classification of coastal and marine environments," IUCN Occasional Paper No. 14, International Union for Conservation of Nature and Natural Resources, Morges, Switzerland.

Ray, G. L. (1994). "A conceptual framework for the evaluation of coastal habitats," Technical Report EL-94-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Reed, A., Davison, M. A., and Kraege, D. K. (1989). "Segregation of brent geese *Branta bernicla* wintering and staging in Puget Sound and the Strait of Georgia," *Wildfowl* 40, 22-31.

Riggs, S. (1983). "*Zostera japonica* and *Zostera marina*: Comparison of biomass and faunal communities," Student report, Huxley College of Environmental Studies, Western Washington University, Bellingham, WA.

Riggs, S. 1992. "Distribution of *Spartina alterniflora* in Padilla Bay, Washington, in 1991," Padilla Bay National Estuarine Research Reserve Technical Report No. 3, Padilla Bay National Estuarine Research Reserve, Mount Vernon, WA.

Ruckelshaus, M. H. (1988). "The effects of habitat characteristics on mussel growth in Padilla Bay, Washington," Padilla Bay National Estuarine Research Reserve Reprint Series No. 8, 1990, M.S. thesis, University of Washington, Seattle.

Ruckelshaus, M. H., Wissmar, R. C., and Simenstad, C. A. (1988). "Mussel growth and estuarine habitat quality. *Proceedings of First Annual Meeting Puget Sound Res*. Puget Sound Water Quality Authority, Seattle, WA, 463-472.

Ruckelshaus, M. H., Wissmar, R. C., and Simenstad, C. A. (1990). "Sources and fates of organic matter: Utilization of eelgrass carbon by estuarine bivalves." *Proceedings of the California Eelgrass Symposium Chula Vista, California, 27 May 1988*. K. W. Merkel and R. S. Hoffman, ed., Sweetwater River Press, National City, CA, 13-20.

__________. (1993). "The importance of autotroph distribution to mussel growth in a well-mixed, temperate estuary," *Estuaries* 16, 898-912.

Scheffer, V. B., and Slipp, J. W. (1944). "The harbor seal in Washington State," *Am. Midl. Nat.* 32, 373-416.

Scott, D. B. (1973). "Recent benthonic Foraminifera from Samish and Padilla bays, Washington," M.S. thesis, Western Washington University, Bellingham, WA.

__________. (1974). "Recent benthonic Foraminifera from Samish and Padilla bays, Washington," *Northwest Science* 48, 211-218.

Simenstad, C. A., Cordell, J. R., Wissmar, R. C., Fresh, K. L., Schroder, S. L., Carr, M., Sanborn, G., and Burg, M. (1988). "Assemblage structure, microhabitat distribution and food web linkages of epibenthic crustaceans in Padilla Bay National Estuarine Research Reserve, Washington," FRI-UW-8813, Padilla Bay National Estuarine Research Reserve Reprint Series No. 9, 1990 (Final report to NOAA/MEMD Grant No. NA86AA-D-CZ027), University of Washington, Fisheries Research Institute, Seattle, WA.

Simenstad, C. A., Miller, B. S., Nyblade, C. F., Thornburgh, K., and Bledsoe, L. J. (1979). *Food web relationships of northern Puget Sound and the Strait of Juan de Fuca, a synthesis of the available knowledge.* EPA 600/7-79-259, U.S. Environmental Protection Agency, Washington DC.

Thom, R. M. (1988). "Benthic primary production in the eelgrass meadow at the Padilla Bay National Estuarine Research Reserve, Washington," FRI-UW-8808, Padilla Bay National Estuarine Research Reserve Reprint Series No. 10, 1990 (Final report to Marine & Estuarine Management Division, NOAA, Grant No. NA86AA-D-CZ027), University of Washington, Fisheries Research Institute, Seattle, WA.

_________. (1990). "Spatial and temporal patterns in plant standing stock and primary production in a temperate seagrass system," *Bot. Mar.* 33, 497-510.

_________. (1992). "Accretion rates of low intertidal salt marshes in the Pacific Northwest," *Wetlands* 12, 147-156.

Thom, R. M., and Albright, R. G. (1990). "Dynamics of benthic vegetation standing-stock, irradiance, and water properties in central Puget Sound," *Mar. Biol.* 104, 129-141.

Thom, R. M., and Hallum, L. (1990). *Long-term changes in the areal extent of tidal marshes, eelgrass meadows and kelp forests of Puget Sound.* EPA 910/9-91-005, FRI-UW-9008, University of Washington, Fisheries Research Institute, Wetland Ecosystem Team, Seattle, WA.

Thom, R. M., Miller, B., and Kennedy, M. (1991). "Temporal patterns of grazers and vegetation in a temperate seagrass system," FRI-UW-9122, Padilla Bay National Estuarine Research Reserve Reprint Series No. 15, University Washington, Fisheries Research Institute, Seattle, WA.

Thursby, G. B., and Harlin, M. M. (1982). "Leaf-root interaction in the uptake of ammonia by *Zostera marina*," *Mar. Biol.* 72, 109-112.

Trumble, R., Pentilla, D., Day, D., McAllister, P., Boettner, J., Adair, R., and Wares, P. (1977). "Results of herring spawning ground surveys in Puget Sound, 1975 and 1976," Washington Department of Fisheries, Progress Report No. 21.

Turner, D. O. (1980). "Investigation of the tidal soils of Padilla Bay," Bulletin 0885, College of Agricultural Research Center, Washington State University.

U.S. Department of Commerce, National Oceanic Atmospheric Administration Office, and Washington State Department of Ecology. (1980). *Final environmental impact statement, proposed estuarine sanctuary grant award for Padilla Bay, Skagit County, Washington to State of Washington.*

Trumble, R., Pentilla, D., Day, D., McAllister, P., Boettner, J., Adair, R., and Wares, P. (1977). "Results of herring spawning ground surveys in Puget Sound, 1975 and 1976," Washington Department of Fisheries, Progress Report No. 21.

Turner, D. O. (1980). "Investigation of the tidal soils of Padilla Bay," Bulletin 0885, College of Agricultural Research Center, Washington State University.

U.S. Department of Commerce, National Oceanic Atmospheric Administration Office, and Washington State Department of Ecology. (1980). *Final environmental impact statement, proposed estuarine sanctuary grant award for Padilla Bay, Skagit County, Washington to State of Washington.*

Valiela, I., Foreman, K., LaMontagne, M., Hersh, D., Costa, J., Peckol, P., DeMeo-Anderson, B., D'Avanzo, C., Babione, M., Sham, C., Brawley, J., and Lajtha, K. (1992). "Couplings of watersheds and coastal waters: Sources and consequences of nutrient enrichment in Waquoit Bay, Massachusetts," *Estuaries* 15, 443-457.

Washington State. (1989). *7 December 1989. Washington Administrative Code, Chapter 16-750, State noxious weed list and schedule of monetary penalties*. Washington State, Olympia, WA.

Webber, H. H., Mumford, T. F., and Eby, J. (1987). "Remote sensing inventory of the seagrass meadow of the Padilla Bay National Estuarine Research Reserve. Areal extent and estimation of biomass," Padilla Bay National Estuarine Research Reserve Reprint Series No. 6, Reprinted 1990 (Final report to Marine & Estuarine Management Division, NOAA grant no. NA86AA-D-CZ027), Western Washington University, Huxley College of Environmental Studies, Bellingham, WA.

Wiggins, J. R. (1992). "The effect of landfill leachate from Padilla Bay on the abundance of epibenthic harpacticoid copepods and sediment toxicity measured with the amphipod bioassay (*Rhepoxinius abronius*)," Padilla Bay National Estuarine Research Reserve Reprints Series No. 17, M.S. thesis, Western Washington University, Bellingham, WA.

Wiggins, J., and Binney, E. (1987). "A baseline study of the distribution of Spartina alterniflora in Padilla Bay," Padilla Bay National Estuarine Research Reserve Reprint Series No. 7, Reprinted 1990, Report to Washington Department of Ecology, Padilla Bay National Estuarine Research Reserve.

Williams, S. L., and Ruckelshaus, M. H. (1993). "Effects of nitrogen availability and herbivory on eelgrass (*Zostera marina*) and epiphytes," *Ecology* 74, 904-918.

Wissmar, R. C. (1986). "Definition of the origins and fates of organic nitrogen in food webs of Padilla Bay National Estuarine Research Reserve," Padilla Bay National Estuarine Research Reserve Reprint Series No. 5, 1990, (Final report to Marine and Estuarine Management Division, NOAA grant no. NA85AA-D-CZ046), University of Washington, Fisheries Research Institute, Seattle, WA.

Zieman, J. C., and Wetzel, R. G. (1980). "Productivity in seagrasses: Methods and rates." *Handbook of seagrass biology: An ecosystem perspective.* R. C. Phillips and C. P. McRoy, ed., Garlands STPM, New York, 87-116.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 1996

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Coastal Habitats in Padilla Bay, Washington: A Review

5. FUNDING NUMBERS

6. AUTHOR(S)
Douglas A. Bulthuis

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Padilla Bay National Estuarine Research Reserve
Shorelands and Coastal Zone Management Program
Washington State Department of Ecology
Mount Vernon, WA 98273

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, MS 39180-6199;
U.S. Army Corps of Engineers
Washington, DC 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
Technical Report
EL-96-15

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The purpose of this report is to review and summarize the published information on habitats in Padilla Bay, Washington. The data are organized by habitat as defined by the Coastal Habitat Classification Scheme. The most extensive and important habitat in Padilla Bay is the Intertidal Aquatic Bed: Rooted Vascular habitat in which about 3,000 ha are covered by the eelgrasses *Zostera marina* and *Zostera japonica*. The eelgrass habitat is highly productive with abundant polychaetes, nematods, harpacticoid copepods, amphipods, and isopods; it is important to Dungeness crab, juvenile chum salmon, surf smelt, Pacific herring, sculpins, and other fishes and to brant, widgeon, pintail, mallard, teal, and other waterfowl. Intertidal sand habitat is also common in Padilla Bay and important to migratory wading birds and harbor seals. These intertidal habitats, along with the subtidal channels that distribute and drain water to and from the intertidal flats, form a mosaic of habitats that support a diverse and abundant estuarine fauna.

14. SUBJECT TERMS
Coastal habitats
Padilla Bay
Washington State

15. NUMBER OF PAGES
65

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
UNCLASSIFIED

18. SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT